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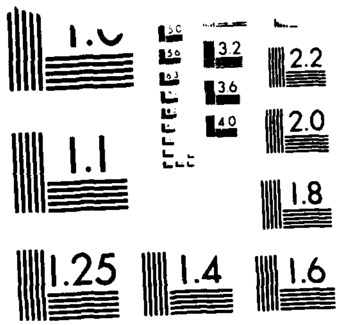

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STREAMBANK PROTECTION AND EROSION CONTROL

BY

JOHN AMARANTIDES

A REPORT PRESENTED TO THE GRADUATE COMMITTEE
OF THE DEPARTMENT OF CIVIL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING

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CHAPTER ONE

INTRODUCTION

1.1 Purpose

The purpose of this report is to identify and offer a better understanding of the key factors affecting the erosion of our stream systems and the adjacent land masses in the continental United States. In order to achieve this, all existing data pertaining to a particular stream system reach under study must be collected and analyzed. This report will cover the various methods of data collection and attempt to establish the relationship between the forces causing the stream bank erosion and/or failure and the resulting type of stream bank erosion and/or failure. In addition, various types of stream bank revetment measures and their costs and construction techniques will be presented.

This chapter will offer a brief background of this country's stream bank erosion problem ,which led to the enactment of Public Law 93-251.

Chapters 2 through 4 deal with identification of the erosion problem, factors and forces causing the erosion and the the erosion or failure mode that it appears through. Chapters 5 and 6 deal with data collection and analysis and the selection and design criteria. Chapters 7 and 8 present a variety of revetment techniques and their cost, while chapter 10 analyzes an actual demonstration project in New England.

1.2 Background [1]

Large-scale efforts to control soil erosion of all forms has been underway since the 1930's. Initial soil conservation efforts were directed toward saving topsoil in agricultural areas, but as the value of land near stream systems increased, the need for more effective bank protection techniques quickly came about. A 1969 study by the U.S. Army Corps of Engineers showed that of the 7 million miles of stream bank in the U.S. 550,000 miles were experiencing some degree of erosion, while 148,000 miles (2%) were experiencing severe erosion problems. This 2% portion of the total stream bank, which was being severely eroded resulted in an annual economic loss that approached $90 million in 1969. In view of this serious economic loss throughout the Nation, the U.S.

Congress passed the Stream Bank Erosion Control Evaluation and Demonstration Act of1974, Section 32, Public Law93-251. This program authorized the U.S. Army Corps of Engineers to conduct a 7 year study to evaluate the causes of stream bank erosion and the effectiveness of existing and new methods of stream bank protection. One must also keep in mind that stream bank protection is a complex area of study and to date there are no standardized engineering manuals with construction plans and specifications for stream bank revetment projects.

Stream systems have an extremely long life cycle from youth to maturity. These stream systems may be straight, but they may bend and loop around as well. They may flow in a broad low swale that barely has the form of a valley, rush between the nearly vertical walls of a narrow steep gorge in a mountain area, or somewhere in between these two extreme cases. The stream water can be clear, or turbid, which is affected by residential and industrial treated wastes as well as stream flow characteristics. Stream systems continually adjust to new impacts in order to maintain their balance. These impacts can be caused by nature or man-made activities or both and play an active part in the streams maturing process. When this balance is upset, the stream will compensate to bring the stream system back into balance most commonly accomplished by stream bank erosion and bed scour or buildup.

Some common situations in which stream systems are thrown out of balance are:

A. When a dead tree naturally topples into the stream or local residents dump heavy wastes over a long period of time. These conditions may cause flow to be diverted to the opposite stream bank, in which flow near the obstruction slows and sediment deposition occurs while the velocity of diverted water increases and attacks the opposite stream bank. The response of the stream to the obstruction results in eroding the opposite bank where flow was redirected.

B. Increase in plowed and planted acreage parallel to stream flow and to the top edge of the stream bank allows rainfall runoff to channel down the bank face. This runoff will erode soil holding shrubs and grass on banks until the natural vegetation is lost leaving a fairly smooth slope with no natural roughness (velocity increases at stream bank soil-water interface during floods and seasonal high water levels) and valuable acreage may be lost landward where crops were planted.

C. Rapid urbanization of a watershed's upstream area decreases rainfall infiltration and increases surface runoff to the stream system. This increases downstream flow during rainstorms forcing the stream to balance itself by increasing its downstream cross sectional area by stream bank erosion and bed scour to accommodate the increased flow. This may be caused by poor planning and assessment of downstream flow conditions by the developer.

The above examples are only a few that could occur when a stream is forced out of balance. Stream systems are in a continuous state of adjustment compensating for an imbalance at one location by making changes at other locations. Stream systems will also compensate for installed bank revetment projects, so care should be taken in the design and selection of bank revetment to prevent serious downstream bank erosion and failure.

CHAPTER TWO

IDENTIFICATION OF STREAM BANK EROSION AND FAILURE

2.1 Types of Stream Bank Erosion and Failure [2]

There are several types of stream bank erosion, which can be natural/or man-induced effecting bank recession, channel deepening, or both. These types of stream bank erosion are:

1. Underwater attack at the toe, leading to bank failure. This type of erosion is most critical during a falling water level at the medium stage or lower.

2. Erosion along the bank- caused by current action.

3. Sloughing of saturated cohesive banks, which are not capable of free drainage during rapid drawdown.

4. Liquefaction (flow slides) in saturated silty and sandy soils.

5. Erosion caused by seepage out of bank at relatively low channel velocities.

6. Erosion of upper bank, river bottom, or both, caused by wave action due to wind or passing boats.

7. Pool fluctuations can be continuous and significant, which adversely affect bank stability.

2.2 Mechanics of Stream Bank Erosion and Failure [3]

The mechanics of stream bank erosion are directly related to the river systems geometry and hydraulic characteristics. Figure 1 depicts that the highest water velocities and deepest section of the channel are at bends where the thalweg lies closest to the concave bank, while figure 2 shows that during a stream's flood stage the highest water velocity lies closest to the convex bank. The maximum water velocity occurs just below the water surface while velocities along bank water interface vary dependent on type of covering (bare to dense vegetation). Velocity decreases as vegetative covering increases.

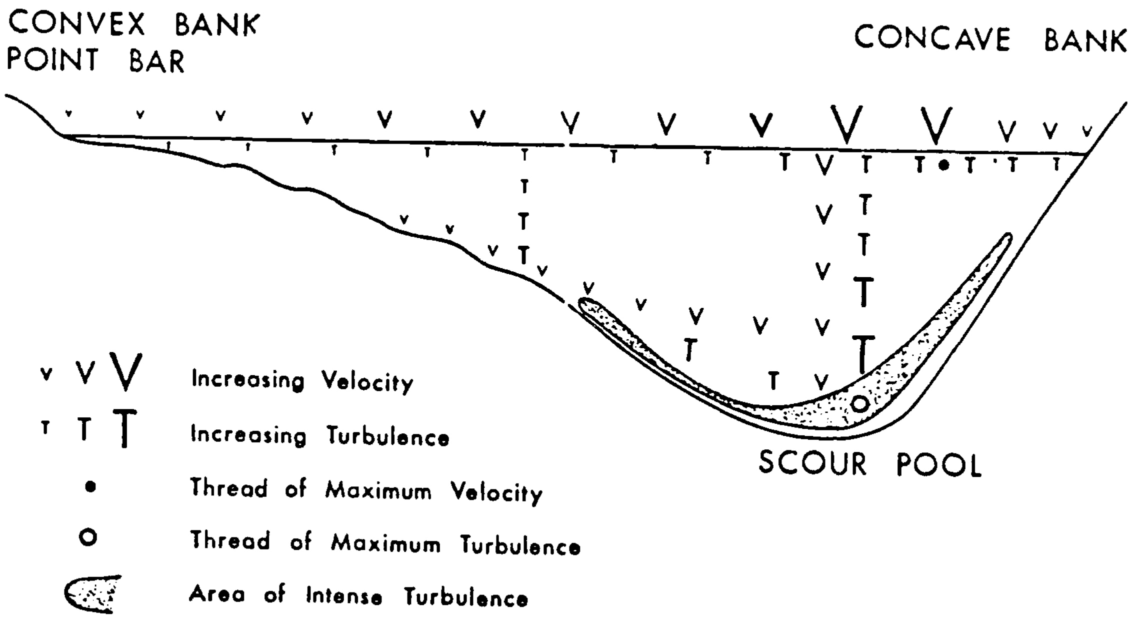


Figure 1. Velocity and turbulence in a river bend (Source 2)

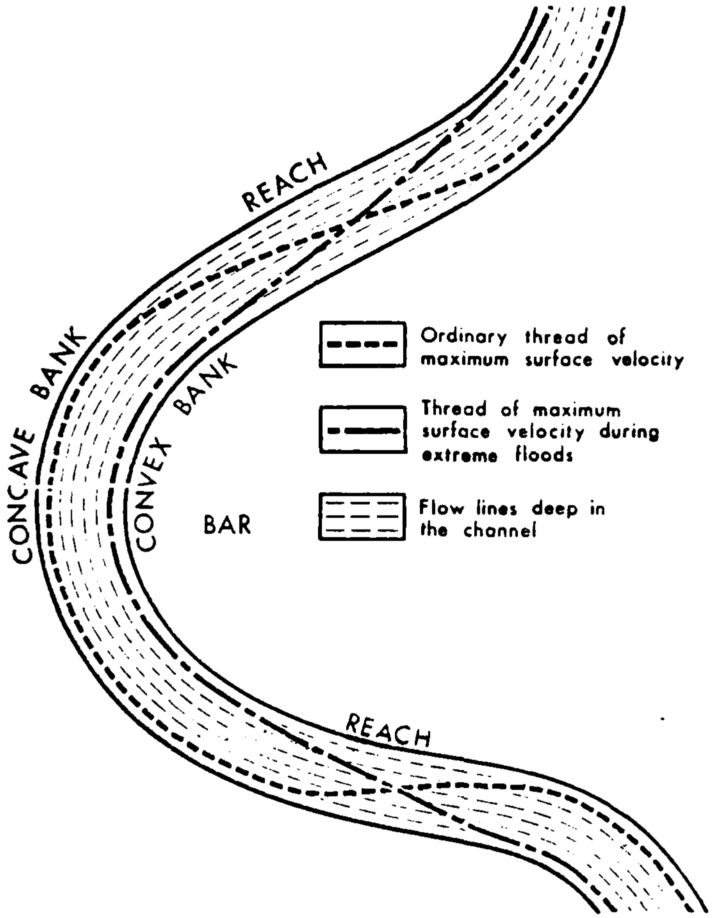


Figure 2. Location of maximum surface velocity during normal and flood flows (Source 2)

2.3 Variables Causing Stream Bank Erosion [4]

The hydraulic parameters affecting stream bank erosion are:

A. Fluid Properties

1. Specific Weight
2. Temperature/Viscosity

B. Flow Characteristics

1. Discharge
2. Duration
3. Frequency
4. Velocity
5. Velocity Distribution
6. Turbulence
7. Shear Stress
8. Drag Force
9. Lift Force
10. Moment Force

The bed and bank material parameters affecting stream bank erosion are:

A. Bed and bank materials

1. Size
2. Gradation
3. Shape
4. Specific Weight

B. Characteristics of bank

1. Non-cohesive
2. Cohesive
3. Stratified
4. Rock
5. Height

The subsurface flows, wind wave and boat wave parameters affecting stream bank erosion are:

A. Wave forces

B. Seepage forces

C. Piping

The climatic parameters affecting stream bank erosion are:

A. Freezing

1. Ice Thickness
2. Duration and Frequency

B. Freeze thaw cyclic loading

C. Permafrost

The biological parameters affecting stream bank erosion are:

A. Vegetation

1. Trees
2. Shrubs
3. Grass

B. Animal life

The man-induced factors affecting stream bank erosion are:

A. Pool fluctuations caused by Hydro power plants

B. Agricultural activities

C. Mining

D. Transportation

E. Urbanization

F. Drainage

G. Floodplain Development

H. Recreational boating

CHAPTER THREE

DISCUSSION OF FACTORS AND FORCES CAUSING STREAM BANK EROSION AND FAILURE

3.1 Hydraulic Factors [5]

Hydraulic factors affecting stability are the specific weight, temperature and viscosity of the fluid and its suspended sediment. Suspended sediment in the flow increases the specific weight and the apparent viscosity of the fluid, which directly affect the velocity, velocity distribution and shear stress. These characteristics ultimately affect the rate of channel erosion.

In general a river channel reaches an equilibrium of bank stability over time so that during periods of low flow there is very little erosion and during periods of intermediate flow some bank erosion and some deposition occur. It is during major flood events that major erosion and stream relocation occur.

The duration of a particular discharge is more important than the magnitude, except for very large floods which occur infrequently.

3.2 Channel Geometry [6]

Channel geometry of a river cross section is an excellent indicator of its erodibility and stability. River erodibility and stability is affected by depth and width of channel (figure 3), type of flow (figure 4), slope of energy gradient, geologic controls and stream bank surface and subsurface vegetation which are dependent on channel geometry.

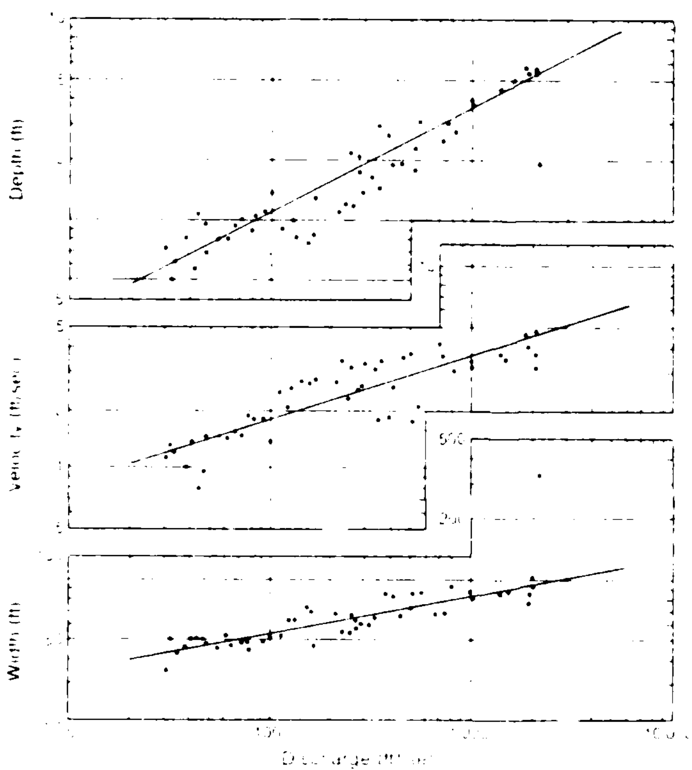


Figure 3. Changes of width, depth, and velocity with discharge at a specific river station: Seneca Creek at Dawsonville, Maryland. The drainage area of this stream is about 260 km^2. Discharge is given in cubic feet per second (Source 38)

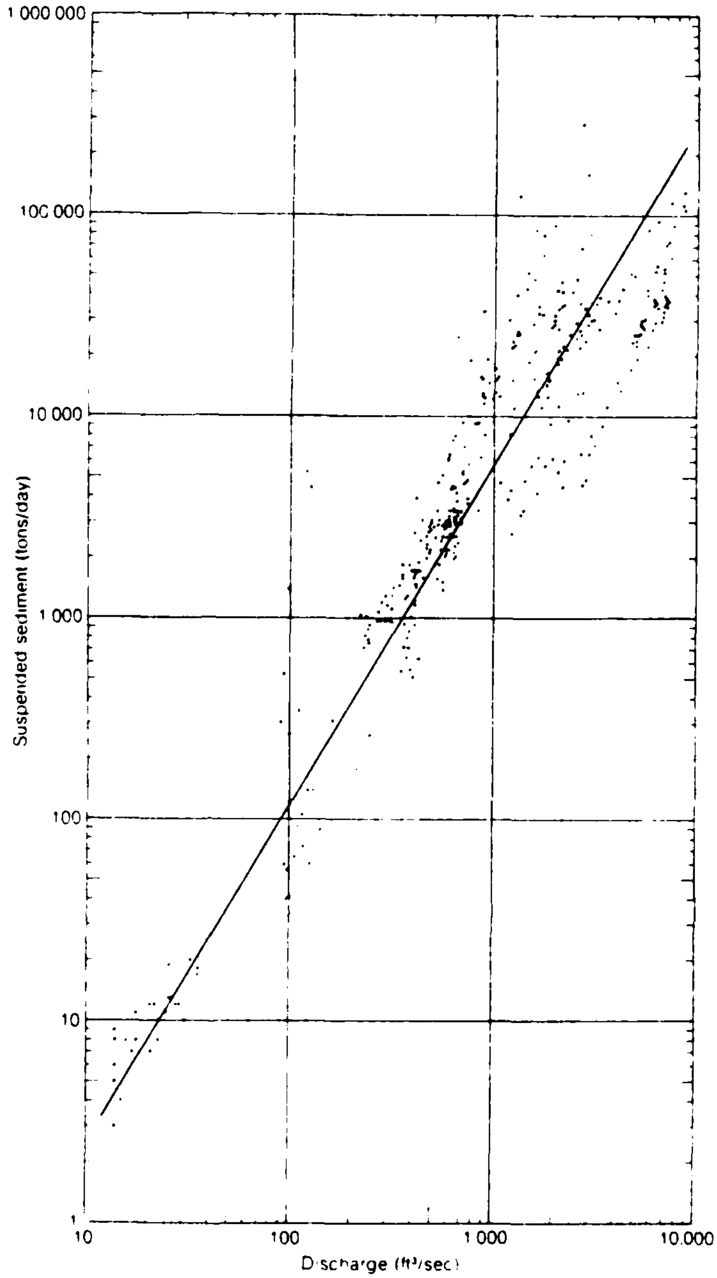


Figure 4. Increase of suspended sediment carried by a river in relation to increased discharge at a specific river station: Rio Grande near Bernalillo, New Mexico. Discharge is given in cubic feet per second (Source 38)

3.3 Velocity Distribution [7]

Velocity, velocity distribution and velocity fluctuations are closely related to discharge flow at any given cross section and are major contributors to stream bank erosion. Velocity is not uniform across a stream channel and even in long straight reaches the thalweg meanders from side to side causing localized erosion dependent on bank materials and the position, strength and duration of the thalweg (thalweg changes position with discharge, time, sediment load, bank characteristics and location). In bends of a stream system the above characteristics are more pronounced on the outer side.

3.4 Tractive Force [8]

The tractive force of concern is the drag force exerted by impingement of the flowing water and its suspended sediment on the stream bank. Tractive force is directly proportional to the square of velocity and is a more sensitive indicator of stream bank erosion. The relationship between velocity U and tractive force per unit area, τ , can be expressed by the following equation (Source 4):

$$U = \frac{1.486}{n \gamma^{1/2}} R^{1/6} \sqrt{\tau} \qquad \text{or} \qquad \tau \propto U^2$$

where R = hydraulic radius

γ = water density

n = Manning resistance to flow coefficent

Since the tractive force is a more sensitive indicator of stream bank erosion, the U.S. Army Corps of Engineers has elected to use it over velocity.

3.5 Moment [9]

Moment is exerted by the stream system onto the stream bank, bank revetment or man made structures. This force can be applied in the form of fluid discharge or iceflow and can be calculated by the product of the mass of the moving object times its change in velocity. In geographic areas subjected to a severe freeze-thaw-flow process it is difficult to design an economic bank protection project, since ice movement with large flows exert forces on the bank line that can cause accelerated erosion, damage to vegetation and loss of installed man made revetment projects.

3.6 Wind and Boat Waves [10]

The magnitude and frequency of wind generated waves is dependent on wind velocity, duration and direction of wind, fetch distance and orientation, surface area and depth of water. On unprotected rivers with long downstream fetch distances subjected to strong winds, the waves can generate sufficient energy to erode exposed stream bank, resuspend fine sediment in shallow areas and possibly adversely affect bank vegetation.

The effects of boat waves are similar to wind waves but are dependent on the size, shape and speed of the boat, frequency of boating and location/position of the boat relative to the stream bank.

The principle causes of erosion by boat and wind waves are:

1. Wave impact on bank

2. Wave washing by wave riding up and down the bank.

3. Water rise and fall in surface elevation (wave phenomenon) causes a measurable inflow and outflow in permeable zones sandwiched between less permeable layers of bank material. This action can lead to piping weakening the bank.

3.7 Stream Bank and Bed Material Factors [11]

A stream bank's resistance to erosion is closely related to the characteristics of the bank material, which is highly heterogeneous in nature. Stream bank material deposits can be broadly classified as cohesive, non-cohesive, and stratified. A cohesive material is more resistant to surface erosion and has low permeability that reduces the effects of seepage, piping, frost heaving and subsurface flow on the stability of the banks, but are more susceptible to undercutting and/or saturation and are more likely to fail due to mass wasting (major slide areas). Non-cohesive bank material is removed grain by grain, with the rate of particle removal (stream bank erosion rate) dependent on direction and magnitude of velocity adjacent to the bank, turbulent fluctuations, the magnitude and fluctuations of the shear stress exerted on the bank and seepage, piping and wave forces. Many of these physical factors may act concurrently. Stratified banks are very common on alluvial rivers and products of past transport and deposition of sediment while the stream system is meandering during it's life cycle as shown in figures 5 and 6. Stratified banks consist of layered materials of various thickness, permeability and cohesion, which make this type of bank susceptible to erosion and sliding due to subsurface flows and piping caused by wave action and pool fluctuations.

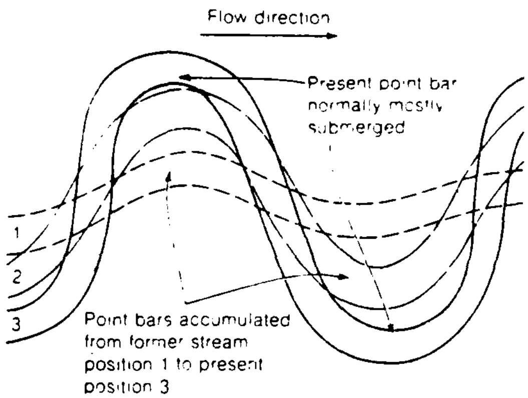


Figure 5. Lateral movement of a river meanders gradually enlarges point bars: 1, 2, and 3 are three stages in the meander movement (source 38)

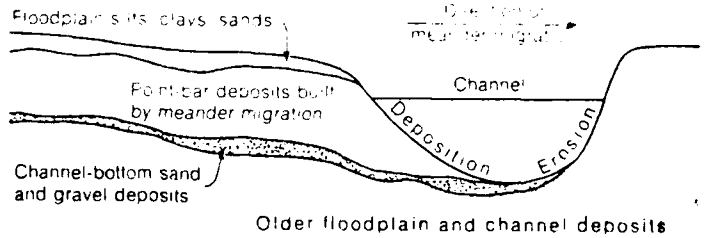


Figure 6. Formation of a river-valley deposits by a meandering channel. As the meanders swing from one side of the valley to the other, they leave a train of point bar and channel deposits from former channel positions, overlain by finer-grained silts, clays, and occasional sands deposited by floods. Point bars are usually cross-bedded, and floodplain deposits are horizontally bedded and ripplemarked (Source 38)

Bed material affects stream bank erosion indirectly. The bed is eroded at the bank toe leaving a higher unsupported bank that is more susceptible to seepage and piping as more lenses of erodible non-cohesive materials are exposed. Size, texture and gradation of the bed material influence the fall velocity, turbulent structure and the velocity field of the flow. Figures 7 and 8 show that as bottom velocity increases, so does the stream's ability to carry larger sized stream bed particles. Figures 9, 10 and 11 show typical cross sections of bed and stream and the various terms pertaining to sediment transportation.

3.8 Climatic Factors [12]

Climatic factors include wide temperature ranges during the year, seasonal heavy rains, freeze-thaw cycles, snow melt, etc.. Extreme temperature fluctuations affect viscosity of the flow, which impact the flows ability to carry suspended sediment. Low temperature ranges increase viscosity and the stream's ability to carry more sediment (increases tractive force and its erosive ability). Northern area stream systems with severe winters are subjected to freeze-thaw cycles and frost heaving which is a phenomenon involving the exposed surface layer of stream bank. The upper most layer of the soil freezes with water in the pores creating a freeze line that the water migrates to and as this layer expands, it forces the overlaying layer upward and out. When the soil thaws it settles back in a loosened state which is easily eroded or it topples over (slumping or sloughing). Seasonal heavy rains of long duration or snow melt may cause extreme flooding, which leads to changes in river cross section and channel location.

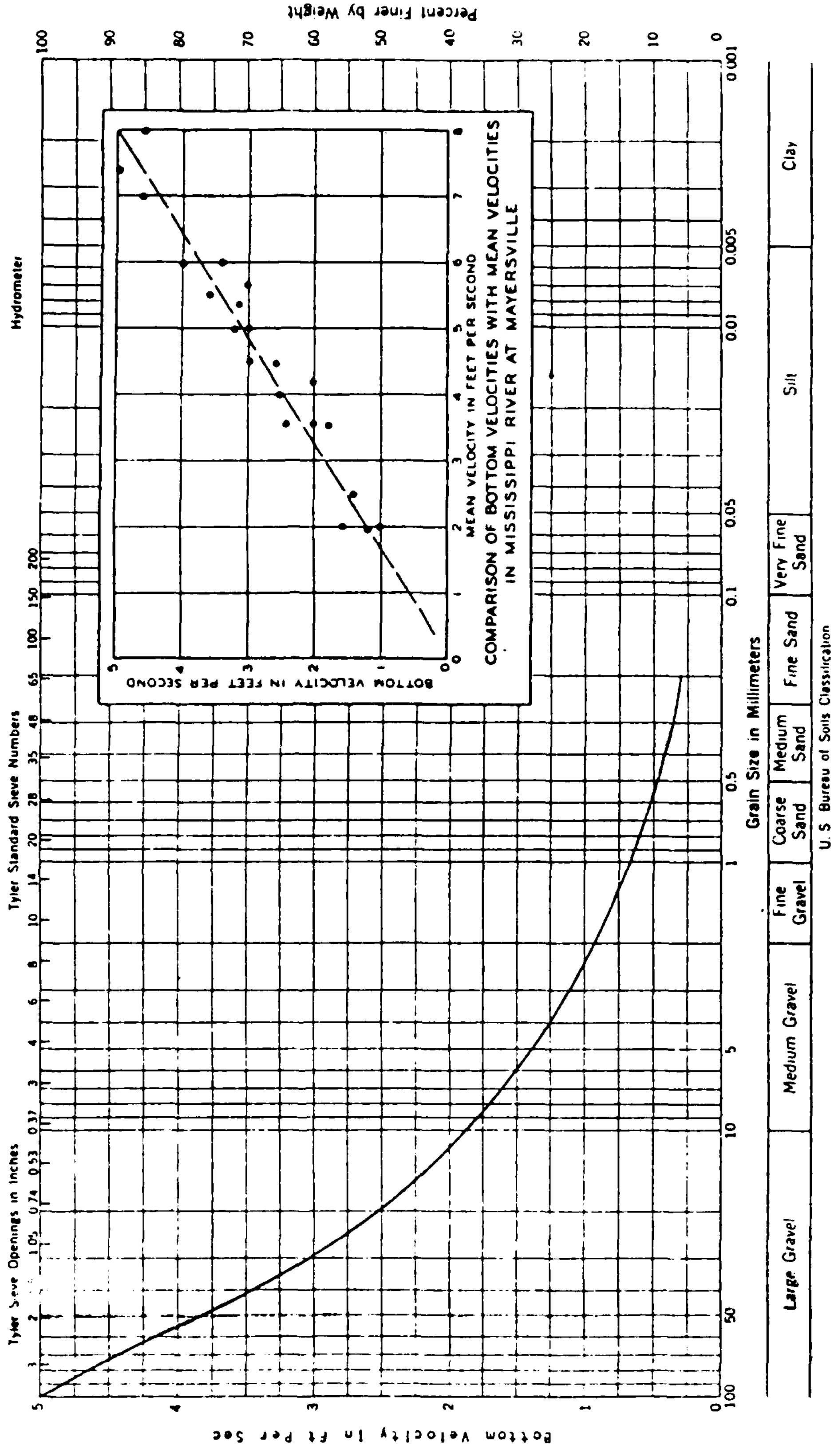


Figure 7. Bottom velocities for initiation of bed-load movement versus grain size (Source 2)

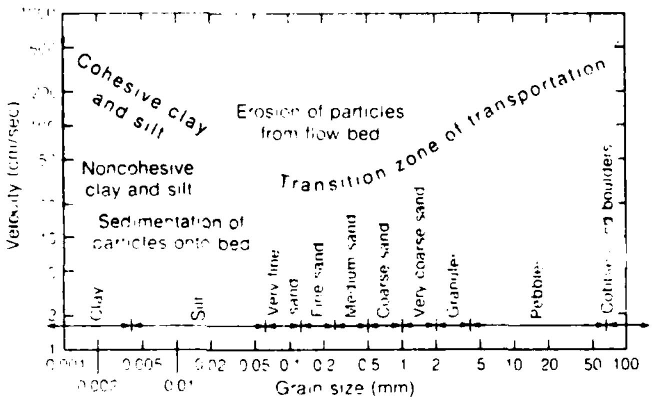


Figure 8. Experimental data on the relation between grain size of particles and velocity of a flow 1 meter deep over a flat, granular bed. For a specific grain size, the lower line is the velocity at which all particles of that size will fall to the bed; the upper line is the velocity at which all particles of that size will continue to be picked up from the bed. The transportation zone is a transition zone in which particles *already suspended* will *remain* in the flow and in which there is no tendency for either erosion or sedimentation to take place. Cohesive behavior of most fine-grained natural materials makes them more resistant to erosion than noncohesive clays and silts (Source 38)

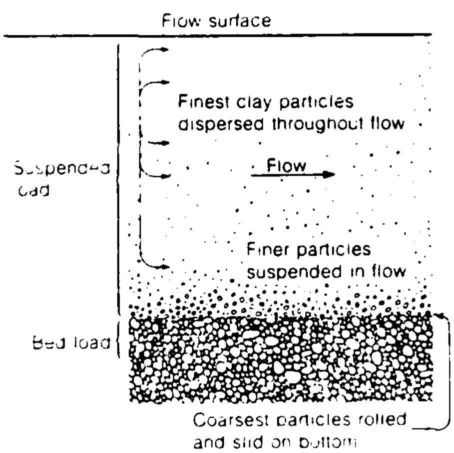


Figure 9. A current flowing over a bed of sand, silt, and clay particles transports these materials as bedload and as suspended load (Source 38)

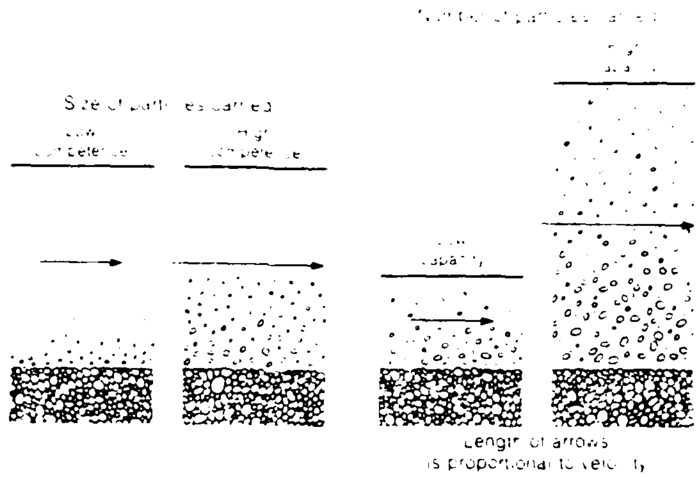


Figure 10. The competence of a current to carry particles is a measure of the largest sizes it can carry. The capacity of a current is a measure of the number of particles it can carry. Competence and capacity are depended on velocity and discharge (Source 38)

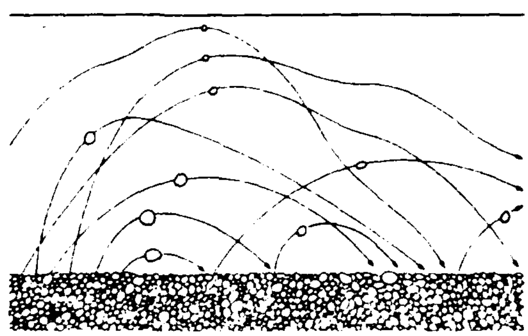


Figure 11. Saltation is an intermittent "jumping" motion of grains. Turbulent eddies pull grains up into the flow, where they travel with the flow for a distance and then fall back to the bed (Source 38)

CHAPTER FOUR

STREAM BANK EROSION AND FAILURE MODES

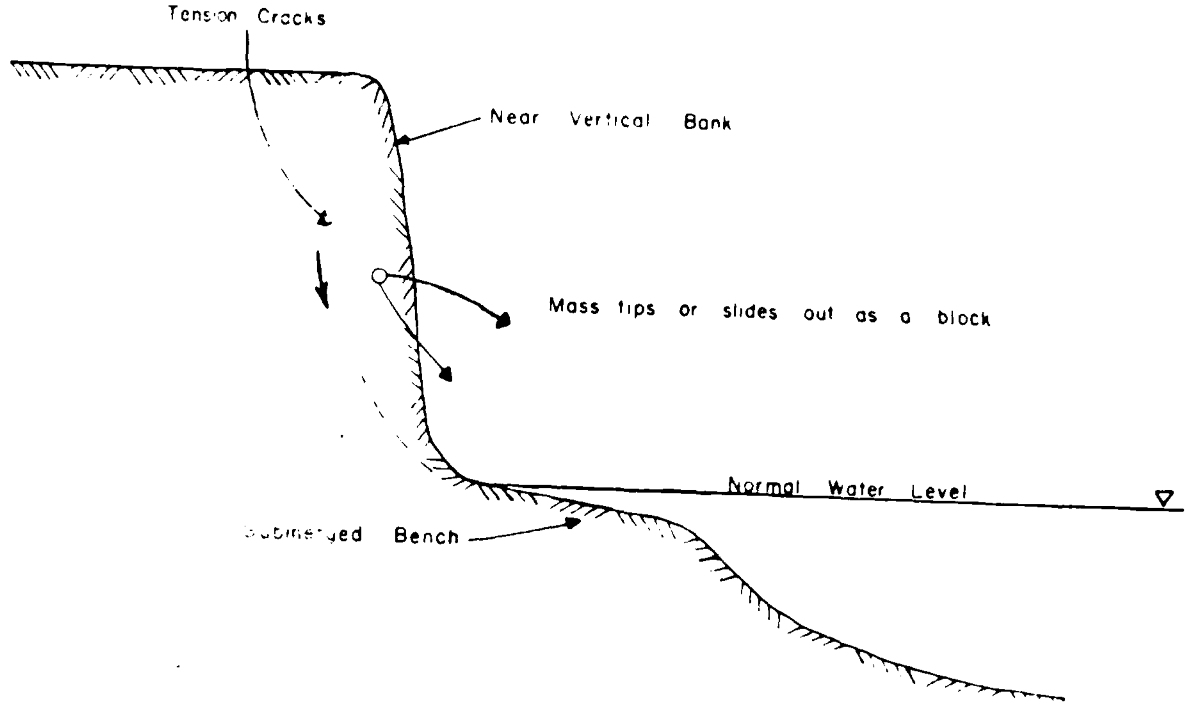
4.1 General

The U.S. Army Corps of Engineers under the stream bank Erosion Control Evaluation and Demonstration Act has evaluated and collected data from numerous stream systems throughout the continental U.S. and has classified stream bank erosion and failure modes into the following six study groups;

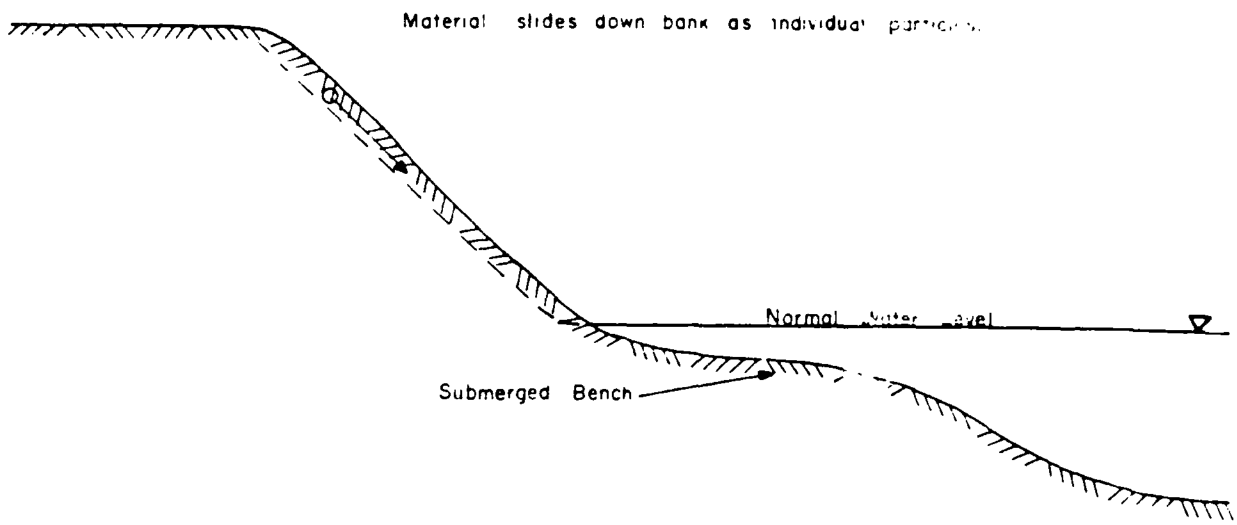
1. Mass Wasting
2. Sloughing
3. Undercutting
4. Headcutting
5. Washing (aggradation/degradation)
6. Cut off meander (oxbow)

4.2 Mass Wasting [13]

Mass wasting is a large mass of soil that slips along a failure plane in the stream bank material. A decrease in the bank material's shear strength causing this type of failure could be attributed to swelling clays due to absorption of water, increase in groundwater pressure from within the bank and minor movements of the soil or creep. While swelling of clays or indications that excessive groundwater pressure is building in the stream bank cannot be directly observed, tension cracks that run parallel to the stream can be directly observed. An increase in the shear stress can also cause mass wasting as a result of changes in channel shape caused by scour or erosion of the bank face, increase in surcharge loads placed at the top of the bank by man and rapid drawdown of water against the bank face. As the bed of the channel is scoured out, the bank height increases and may fail under it's own weight. In periods of high water when banks become saturated (rainfall, runoff, groundwater, etc.) there is a balance between the water covering the bank face and the bank keeping the two in equilibrium, until the stream experiences drawdown (rate of drawdown is critical) and if the soil cannot drain quick enough it can create a pressure imbalance that may cause bank failure. Figures 12, 13 and 14 demonstrate the mass wasting failure mode.



12A. A large mass of soil that slips along a curved path in the stream bank



12B. A relatively thin soil layer sliding down the stream bank

Figure 12. Stream bank erosive action (Source 4)

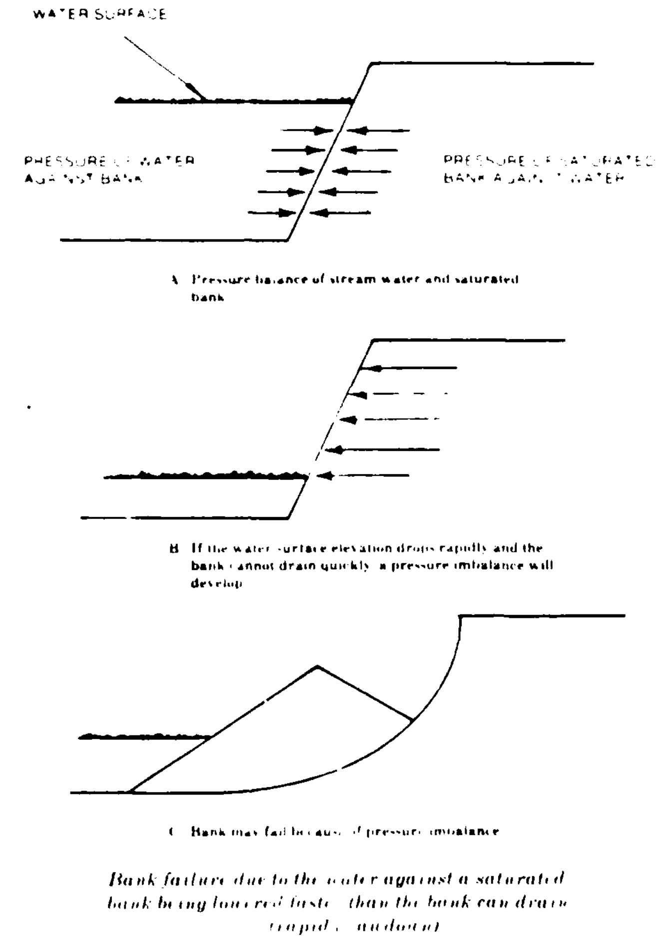
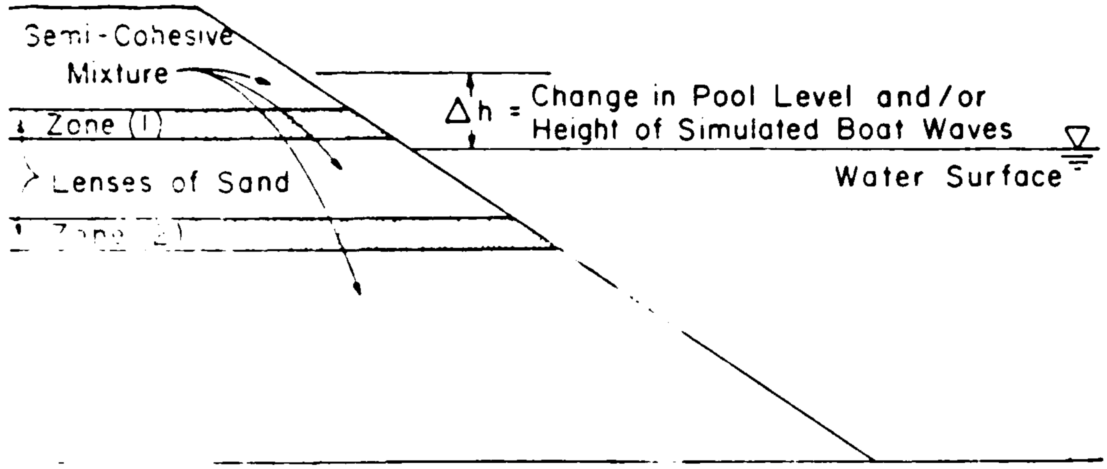
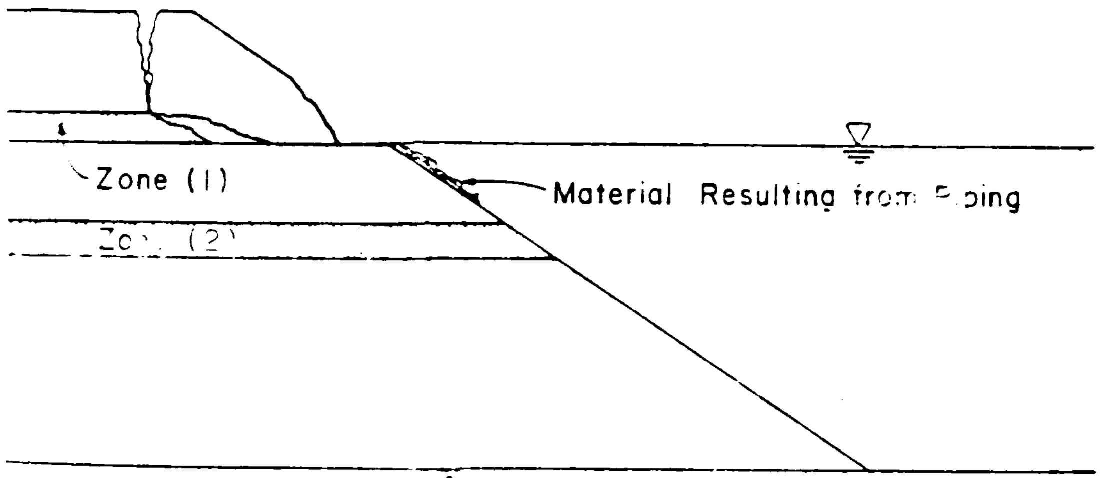


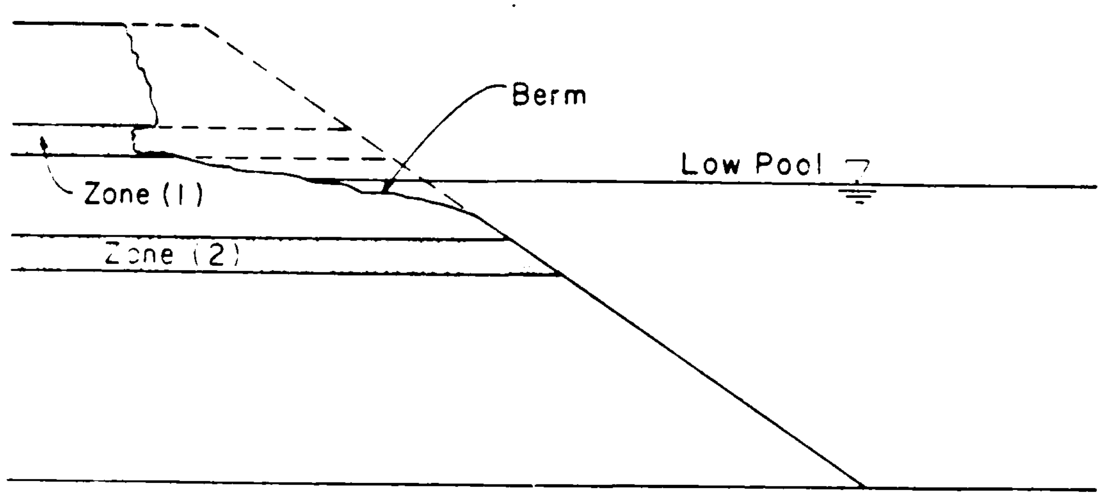
Figure 13. Seepage failure due to imbalance in groundwater pore water pressure (Source 1)



14A. Stratified stream bank



14B. Development of tension crack



14C. Development of berm

Figure 14. Sketch of physical model study (Source 4)

4.3 Sloughing

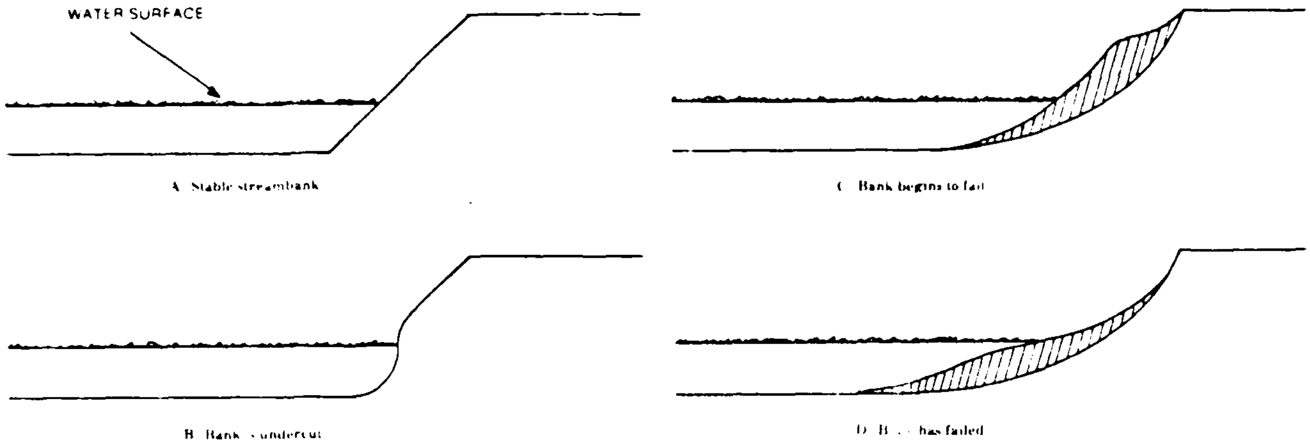
Sloughing is mass wasting involving small amounts of material moving as clumps on stream banks. The failure mechanism is the same as mass wasting, but is further complicated/caused by partially protected banks by vegetative growth, heterogeneous characteristics of bank materials and the freeze-thaw and seasonal cyclic process in the northern colder regions.

4.4 Undercutting

Undercutting is a loss of a non-cohesive soil layer caused by water level fluctuations, wave action, piping, or combination of two or more factors. As the non-cohesive soil layer is subjected to variation of water level, the particles are eroded away eventually causing tension cracks that develop and lead to ultimate bank failure as shown in figure 15.

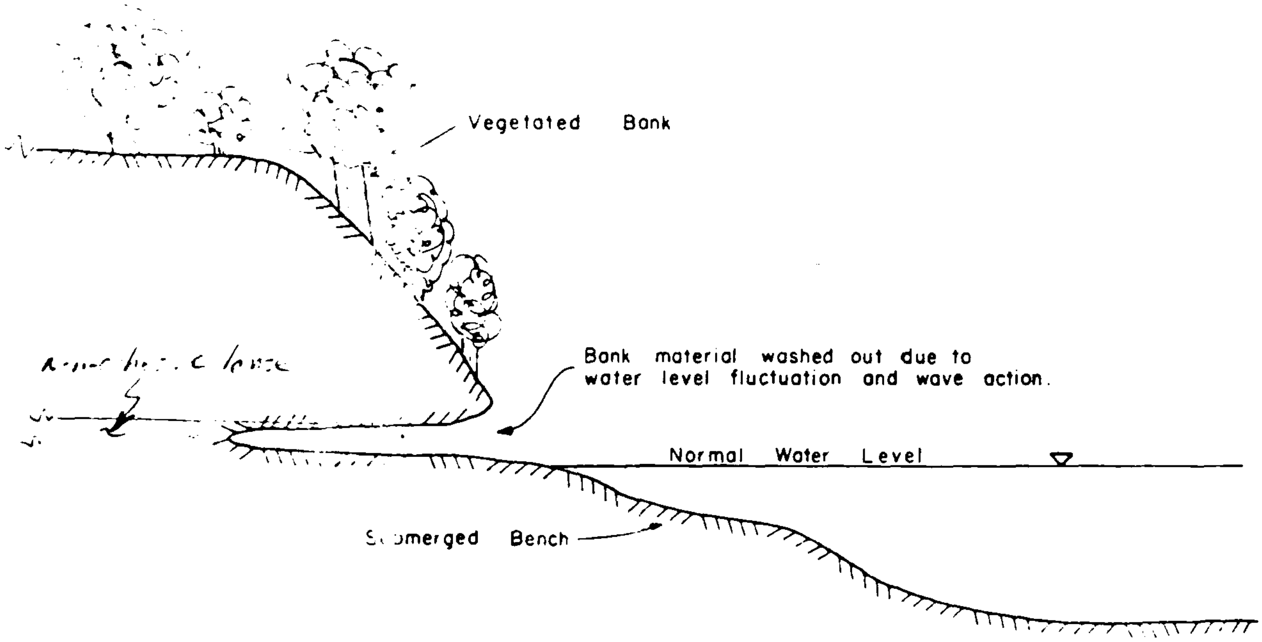
4.5 Headcutting

Headcutting is the upslope progression of a channel bank caused by runoff, bank seepage outflow or natural toppling of trees on banks resulting in "V" notches in the banks. Headcutting is shown in figure 16.



Failure of streambank due to undercutting at the toe.

15A. Undercutting of a relatively homogeneous cohesive or noncohesive streambank



15B. Undercutting of a stream bank caused by the erosion of a noncohesive soil layer

Figure 15 The undercutting failure mode (Sources 1 and 4)

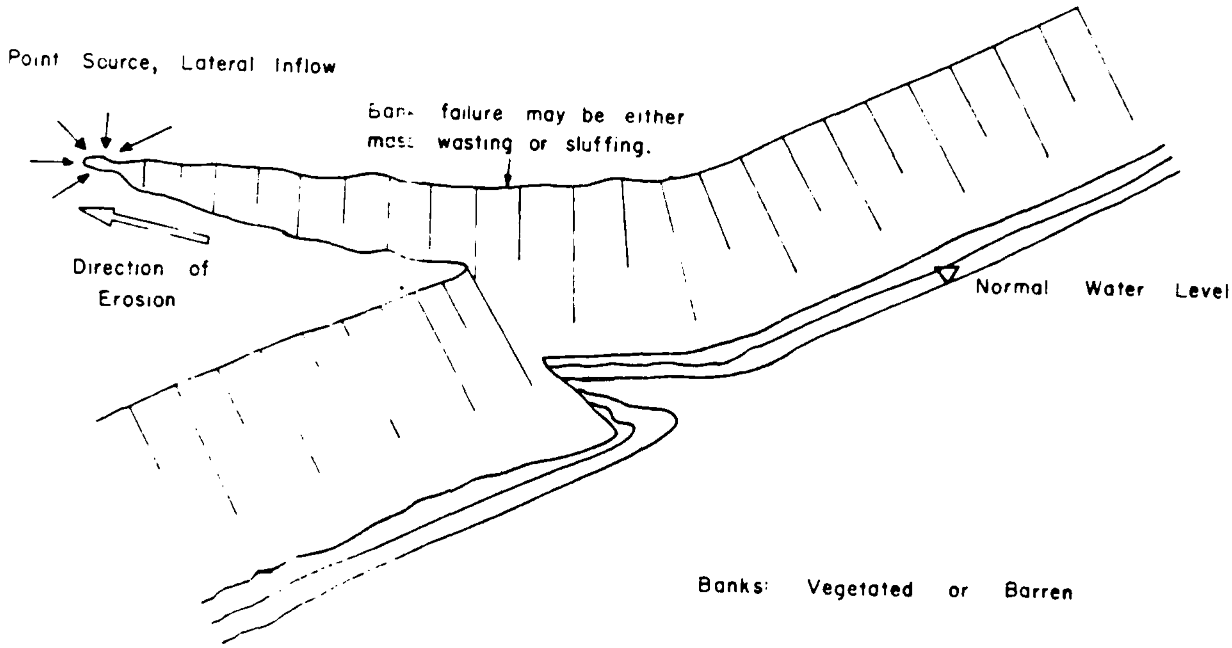
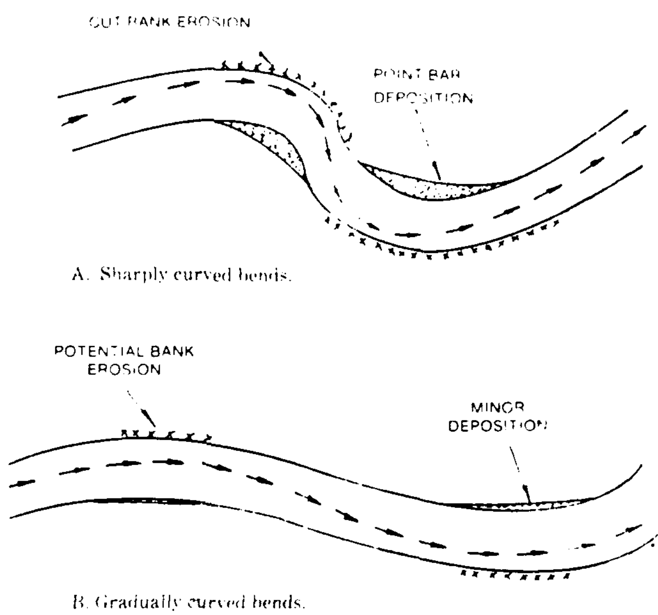


Figure 16. Headcutting on a vegetated or barren stream bank (Source 4)

4.6 Washing

Washing is the removal of soil particles by water level fluctuations, wave action and stream flow at the bank/fluid interface. Erosion as a function of degradation is more pronounced on bends and occurs on the concave bank, while point bars form due to aggradation on the convex bank. The washing process is shown in figures 17 and 18.



Sharply and gradually curved bends under normal flow conditions. Arrows indicate the path of the maximum stream velocity. During floodflow this path moves across the channel against the point bar.

Figure 17. Washing process; aggradation and degradation (Source 1)

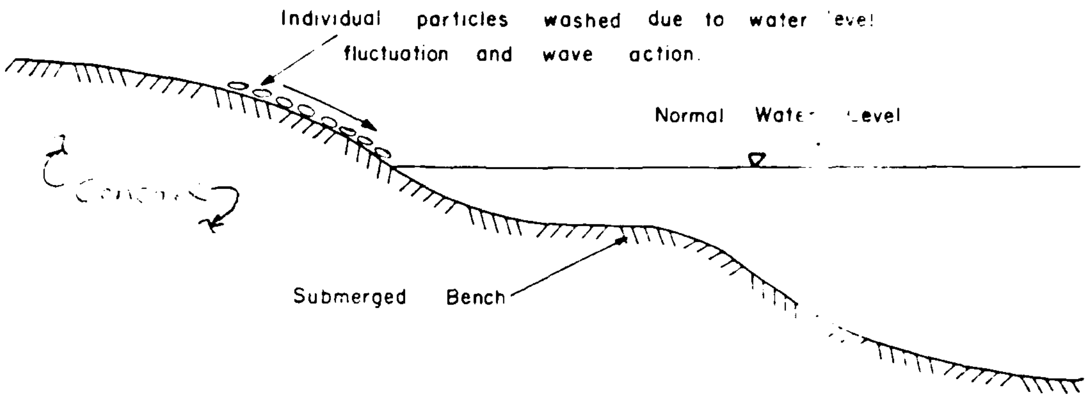


Figure 18. In the washing process material is removed from the concave bank, while material is deposited on the convex bank

(Source 4)

4.7 Cutoff Meanders

Cutoff Meanders (oxbows) occur abruptly during a stream system's flood stage when water levels are higher than banks and abnormally high flows causing rivers to break through banks isolating island type land masses as shown in figure 19.

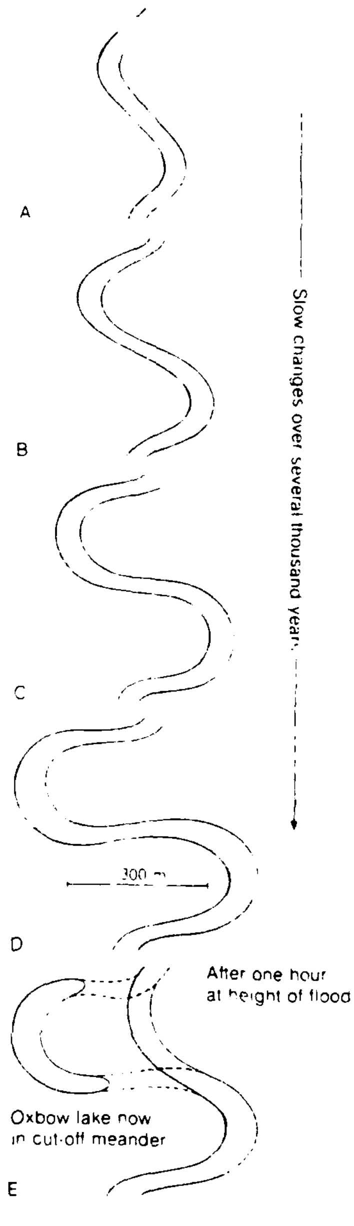


Figure 19. A meander loop of a river slowly accentuates its bends over hundreds of years (a to b), but in one hour's time, at the height of a flood, may break through its banks (d to e) to cut off a meander and isolate an oxbow lake (Source 38)

CHAPTER FIVE

INVESTIGATION OF STREAM SYSTEM

5.1 General [14]

Once a particular stream system reach has been defined as a problem area, a preliminary investigation should be conducted to define the scope and character of the damage. This preliminary investigation would then be used to decide whether protection work is at all feasible, and to determine what additional studies and planning are needed. Historical and future aspects of the erosion problem should be considered as well as present aspects. Information on the stream systems physical characteristics of the problem should include: losses of adjacent land masses and improvements due to erosion or other damage to the stream system; inadequacy of channel flow capacity and reductions in environmental quality with regard to the water, vegetation , wildlife, recreation and agriculture.

In order to conduct a thorough hydraulic, hydrologic, and sediment movement evaluation of the stream system, data must be collected in the following categorized areas: topographic and hydrographic; geologic and soils; hydrologic, hydraulic and sediment; environmental and climatological. Basically, one must attain an understanding of the past and present behavior of the stream to correctly evaluate problem causes and solutions. The field reconnaissance should include a search for flood markers, natural and man made, cultural factors that would affect the channel system, surface and subsurface soil sample taken, photographs and records of pertinent dimensions and features of bank slope and surrounding area. It is important that this study also include sufficient stream bank reaches upstream and downstream of the problem reach, since corrective action taken in one area may simply shift the problem upstream or downstream.

5.2 Topographic and Hydrographic Data [15]

This information is required to correctly establish the channel and valley alignments, cross sections and profiles, through the problem areas as well as above and below it. Aerial photography, topographic and hydrographic maps and charts can be used to examine general channel alignment and historical information on meandering. In addition to the data collection, reference markers should be established to monitor active bank caving and vegetative cover types and sizes should be identified and documented. A typical topographic map and a hydrographic chart are shown in figures 20 and 21.

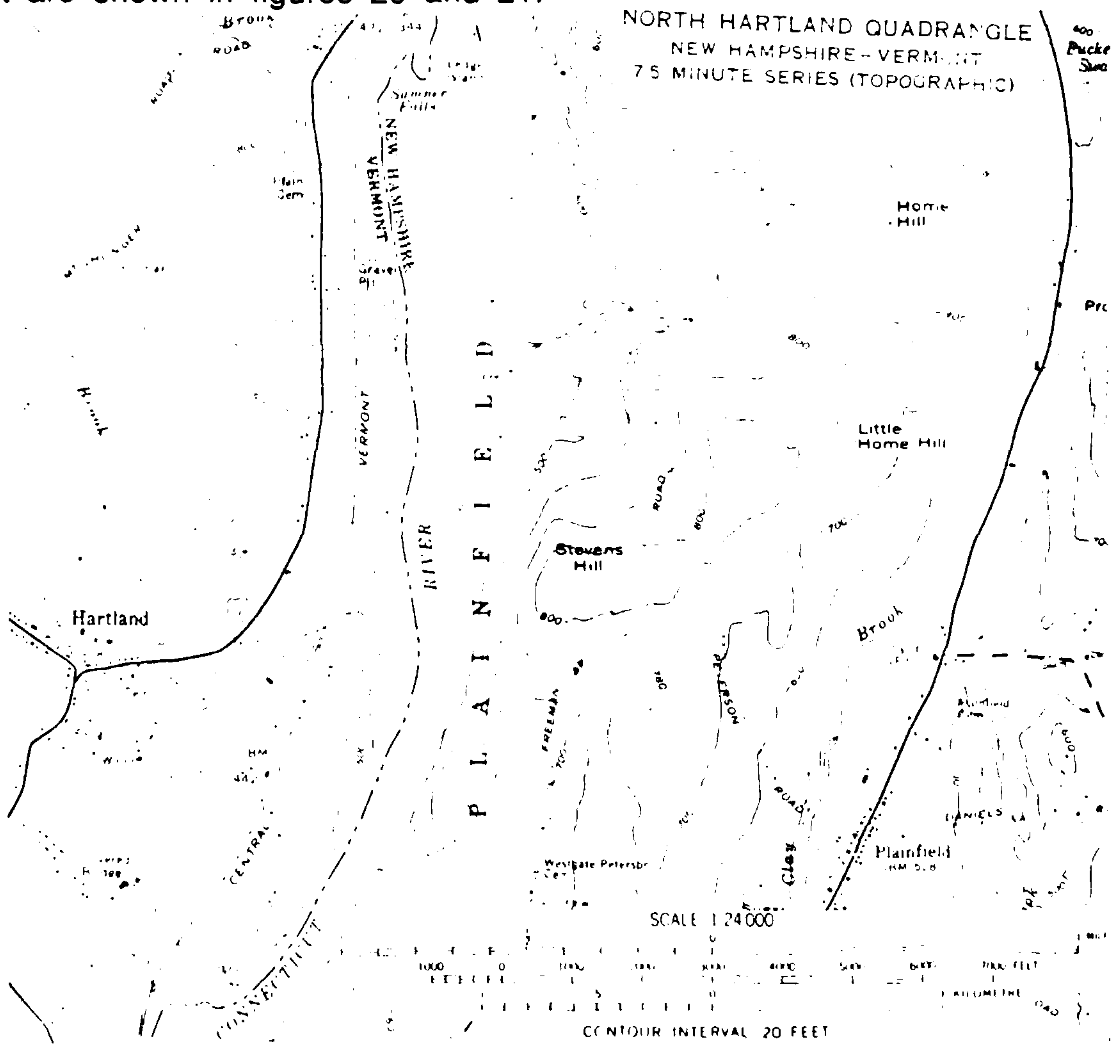


Figure 20. Typical topographic map (Source 4)

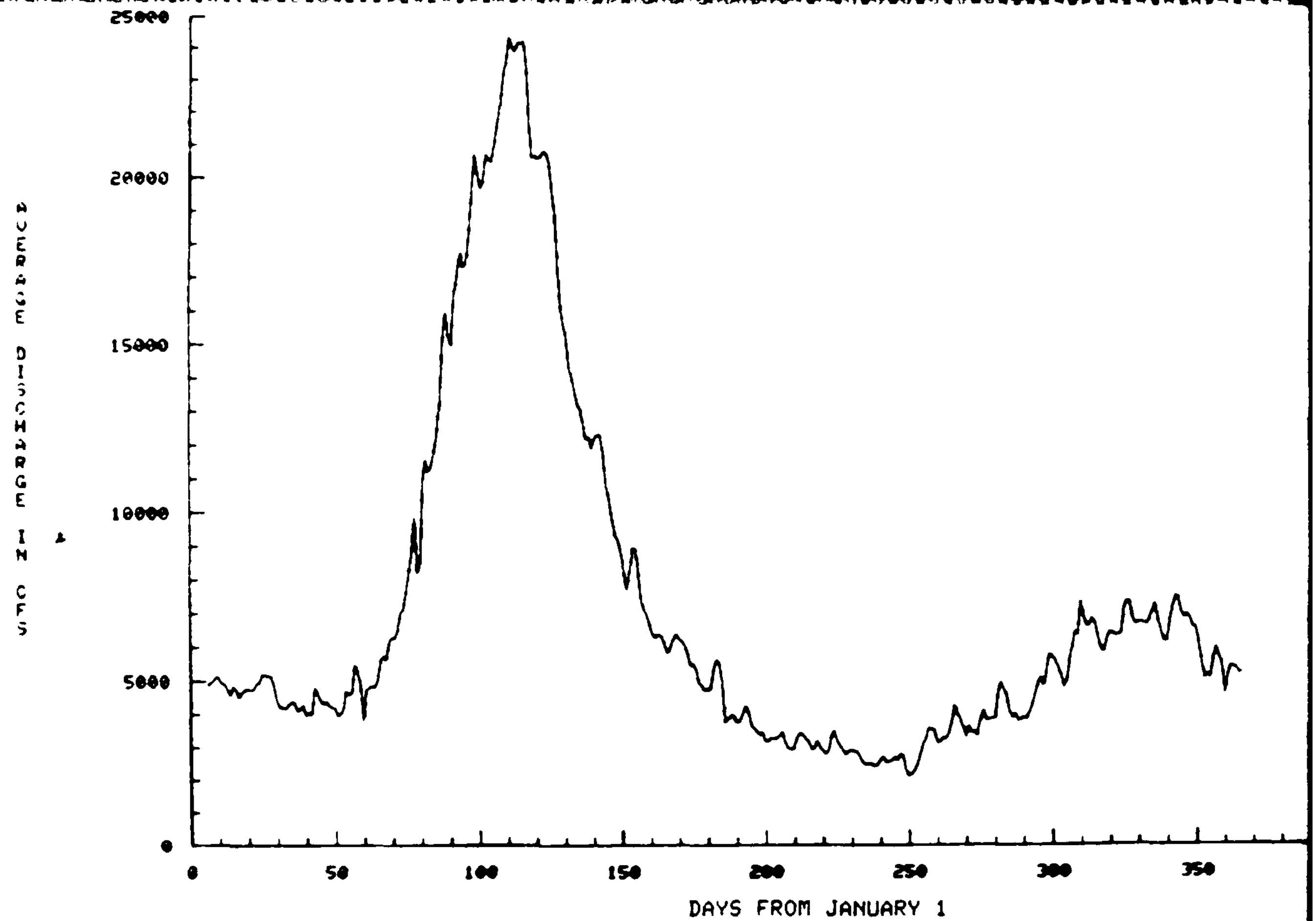


Figure 21. Typical average hydrograph for White River Junction, Vermont (Source 4)

5.3 Geologic and Soils Data [16]

Extensive geologic, geomorphic and soils data is available through the local U.S. Geological Survey and Soil Conservation Service. This information should be used to tailor a subsurface exploration program to the anticipated soil strata. This information is needed to develop the geologic profile and ground water levels in the problem area. Piezometers are typically used to gain an understanding of ground water and its changes due to river fluctuations and rainfall at the site. Banks suspected of failure resulting from poor subsoils or other internal reasons should be monitored with slope indicators set sufficiently deep to protect the integrity of the test and insure good data. Soil samples obtained from the exploration program should be classified and tested. During the classification work data should be taken to properly identify thin layers of strata of erodible or resistant subsoils along the channel bank and bottom. Insitu permeability tests might be helpful to evaluate permeability characteristics of the stream bank.

5.4 Hydrology, Hydraulic and sediment Data [17]

This information is needed to evaluate stream flow stages, discharges, velocities and sediment conditions in the problem reach, including flow durations, frequencies of peak discharges and any apparent trends caused by climatic cycles, changes in land use, or flow control by dams, levees and channel modifications. Seasonal run off, tributary discharge and man made pool fluctuations would be of primary concern in evaluating the problem area. Historical discharge and current discharge records may be obtained from local governmental agencies, Army Corps of Engineers an ' possibly hydroelectric power plants if they exist. If this information is not available it would require time and money to set up a monitoring program and this may not be cost effective and timely depending on the seriousness of the problem area, in which case data from similar study areas might be used. Once all the information is collected and compiled it is used to develop annual, seasonal, peak and flood stage hydrographs used as a primary source in the analysis of the tractive force and also for weighing the erosive forces causing various types of erosion along the problem reach. A good source of information is hydroelectric power plants since they maintain records on both pool stages and variation of pools stages with respect to time. A typical hydrographic chart was shown previously in figure 21.

5.5 Environmental Considerations [18]

All available data pertaining to forest land, vegetation types, wildlife, fish habitat, turbidity of the water related to aquatic life, water quality and water temperature should be considered in an environmental impact study. We must keep in mind that impacts of stream bank protection projects are dependent on project location and regional characteristics, and can change stream hydrology sufficiently resulting in adverse impacts throughout the floodplain ecosystem. During initial project planning a wide range of alternatives is generally available and careful attention should be paid at all project stages to avoid conflicts in achieving environmental quality needs versus sound engineering practice.

Concepts that can easily be implemented in design are the use of natural materials for bank protection, vegetative bank cover or combination of both vegetative cover and structural measures. Proper selection of project features can contribute significantly to the aesthetic value of the completed project, while maintaining a riparian buffer zone with adequate access for recreation and wildlife. Construction should be restricted to minimize impacts on the riparian zone, and affected areas should be restored as soon as possible.

The balancing of environmental and engineering considerations while weighing the benefits and costs of various alternatives provides a method to meet both environmental objectives and project needs in the area of bank protection.

5.6 Climatological Data [19]

This type of data is limited to precipitation and air temperature. If extensive discharge data is available for study, then this information would not be necessary to determine watershed yields within the study area.

CHAPTER SIX

SELECTION AND DESIGN OF STREAM BANK PROTECTION PROJECTS

After a thorough review of the detailed investigation of the stream bank erosion problem and analysis of the channel system to determine the cause or causes of the problem, the objectives and course of action should be apparent. We can now begin to formulate, assess and evaluate plans for various types of bank protection methods.

In chapter two we listed the variables that cause stream bank erosion and in chapter three we discussed their effect on the stream systems banks and bed. In the next two paragraphs I will summarize the probable causes of poor stream bank stability and remedial measure alternatives.

The cause or causes in any stream bank problem will probably be within the following general phenomena: [20]

A. Removal of bank and bed materials through considerable ranges of depth and distance along the bank due to high flow velocities.

B. Removal of material in a confined area due to local concentrations of high velocities resulting from the local channel boundary shape.

C. Undercutting of the stream bank due to bed degradation, local channel velocity patterns, and/or low lying strata of weak credible bank materials.

D. Bank sloughing or caving due to stream bank material of varying stability with respect to seasonal vegetative cover or exposure of highly erodible materials.

E. Massive failures of structurally unstable stream banks due to increase and/or decrease in shear strength.

F. Removal of stream bank materials due to wave attack from wind and passing boats.

G. Removal of stream bank materials due to impact attack from ice or debri masses.

H. Removal of stream bank materials caused by fluctuating water levels due to hydropower or flood-control operations.

I. Material loss due to weathering and/or chemical reactions.

J. stream bank material washout due to water entering the channel over its banks and/or rainfall on the stream banks.

K. Removal of submerged bank and bed materials due to increases in the stream system's sediment capacity.

There is a seemingly endless variety of stream bank protection methods to choose from to protect a stream system against one or several erosive problems causing damage and/or stream bank failure. It is therefore extremely important to gather as much knowledge, experience and guidance from all assets past and present. Some good sources are the U.S. Army Corps of Engineers, the Section 32 Program and design directives. Remedial methods in any stream bank problem will fall in the following categories of protection techniques, from which a more specific items can be derived and can often be used in combination: [21]

A. Direct stream bank protection with materials more resistant to erosion than the underlying soil due to greater density, mat-type construction or reinforcement of the bank soils as with vegetation, filter cloth, tires, etc.

B. Dikes or devices to reduce the flow velocities along bank.

C. Dikes or other techniques to reshape the channel alignment locally or extensively so as to direct the flow away from the stream bank, or to reduce sharp channel curvature.

D. Protection of the bank to prevent undercutting.

E. Grade control of the channel bottom.

F. Improving the structural stability of the stream bank or soil mass.

G. Controlling water flow entering channels over its stream bank.

It cannot be stressed enough that any substantial changes to the stream system's original configuration should be given careful consideration so as not to initiate a "domino effect" of new problems resulting from improper analysis and action to solve the original stream reach problem. In order to minimize the "domino effect" in whole-channel improvements as much of the natural channel as possible should be used and the water and sediment flow characteristics throughout the reach should be changed as little as possible.

A range of stream bank protection projects should emerge from consideration of the causes and alternative remedial measures. A preliminary review of the remedial measures will identify a number of impractical schemes as well as satisfactory ones, but those in the middle range which might be questionably satisfactory should also be given careful consideration. As the range of alternatives is reduced, preparation of detailed plans, impacts, costs and resources can proceed. Final remedial project selection should also consider the following: [22]

A. Design guidance from appropriate sources should be carefully reviewed for application to the specific problem and followed closely to avoid adverse results. The U.S. Army Corps of Engineers is responsible to provide technical and engineering assistance to non-Federal public interest groups in developing structural and nonstructural methods of preventing damages attributable to shore and stream bank erosion.

B. Both successful and unsuccessful experience on the same stream system or similar streams can be particularly helpful in selecting protection schemes and detailing plans.

C. Locally available low cost alternative construction materials for the project should be evaluated and used, whenever possible.

D. Constructibility of each project is considered during its design phase. This allows the plans and specifications to be understood and the project constructed with ease. The constructibility review includes analysis of compatibility of design, site, materials, methods, techniques, schedules and field conditions as well as sufficiency of details and specifications, freedom from design errors, omissions, and ambiguities.

E. The anticipated performance of the stream bank protection project should be outlined over its expected life. Extreme consideration should be given to expected ranges and duration of flows, possible land-use changes, materials strength and durability, anticipated maintenance, environmental conditions related to the project, etc.

F. Alternatives of no protective work and nonstructural work should also be investigated. In problem reaches where only low-cost protection can be justified, a lower degree of protection could be provided against a correspondingly lower degree of flooding. This type of protection would require close observation.

The choice of the best alternative stream bank protection project will generally be based on a benefit cost analysis. In many instances, substantial regulation constraints that must be complied with have a significant influence on both the benefits and costs. Consideration of the project economics should include both tangible and intangible factors. Since construction costs are a one time expenditure while maintenance, repair, property values, etc., are annual costs and benefits, an average annual cost analysis over the project's life expectancy should be used for project evaluation. Finally, a decision must be made and documented for future reference in the event of extending the protection or investigating unexpected behavior, which could very well be good and/or bad.

CHAPTER SEVEN

EROSION CONTROL METHODS

7.1 General [23]

Within the continental United States, effective protection of stream banks along navigable waterways is an integral part of the U.S. Army Corps of Engineers mission. This mission places the large responsibility upon them to maintain navigation channels, protect property and improve water quality. It was this responsibility, which resulted in the Section 32 Program Legislation. This legislation allowed for a variety of experiments and studies to be conducted to determine the most effective and economical bank protection "methods" at selected sites nationwide to demonstrate their capability to perform under a broad range of geographical and environmental conditions. The most widely used revetment types, which have found favor in these studies and in the engineering community, are:

A. Stone riprap,

B. Gabions,

C. Articulated concrete mattresses,

D. Erosion-control matting,

E. Fences,

F. Vegetation,

G. Jacks,

H. Bulkheads,

I. Concrete pavement,

J. Transverse dikes,

K. Woven plastic filter cloths.

The use and effectiveness of each of these revetment types will be discussed in more detail in the following sections.

7.2 Stone Riprap [24]

When stone of sufficient size and quantity is available, riprap is usually the first choice among the various stream bank protection methods. A Riprap blanket is flexible and can withstand slight movement of the bank resulting from settling or other minor stream system adjustments. When a section of riprap is damaged or lost it can easily be repaired by placing more stone. The construction is also quite simple with no special equipment or complex placement practices needed. The appearance is natural and is widely accepted in recreational and public areas. Eventually vegetative growth will often appear through the rocks hiding it further as well as adding structural value to the bank and restoring natural roughness.

Riprap consist of rock courses placed along the bank slope (grade if irregular). A bed of gravel or porous filter material is placed first over the sloped bank to allow seepage but prevent migration of bank material. In order for a riprap blanket to be effective under the influence of the storm system's maximum hydraulic flow condition, the bedding material must prevent erosion of the natural bank material through the riprap and resist undercutting and raveling at the blanket ends. Therefore the design objectives necessary to insure bank protection requires:

A. Determination of shape, size and weight of the stones in the riprap blanket to insure stability under designed hydraulic flow conditions.

B. Well-graded bedding material or filter cloth to prevent repaired by placing more stone. The construction is also quite simple with no special equipment or complex placement practices needed. The appearance is natural and is widely accepted in recreational and public areas. Eventually vegetative growth will often appear through the rocks hiding it further as well as adding structural value to the bank and restoring natural roughness.

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A. Determination of shape, size and weight of the stones in the riprap blanket to insure stability under designed hydraulic flow conditions.

B. Well-graded bedding material or filter cloth to prevent erosion of bank material through the blanket.

C. Optimum blanket and bed thickness.

D. Proper termination of the riprap blanket.

Airy's Law has been used to determine several empirical relationships used in the determination of the minimum stone size and weight for use on a specific stream bank to withstand it's maximum hydraulic flow. The determined size and weight are considered median values, such that 50% of the stones used in the riprap blanket must be greater in size and 50% must not weigh less than the median values empirically calculated. Selection of the stone shape is controlled by subjective experience and local available types for use in the riprap blanket. Stone that is block-type and has sharp edges are preferred offering a better fit and good interlocking capability for increased stability. In general no stone should be used with a length-to-width ratio greater than 3 with no more than 25% greater than 2.5 and less than 3.0.

Both quarry-run and graded stone can be used in a riprap blanket, but large stones are usually eliminated or crushed. This will prevent accelerated water flow around a large stone that can scour bed material and possibly remove smaller adjacent stones in the blanket. Gradation of riprap is also extremely important. Poor gradation caused by over sized stones can prevent mechanical interlocking and promote movement of underlying natural materials through the blanket. Poorly graded riprap can still be used, but would require a thicker filter bed of sand, crushed rock, gravel or synthetic filter cloth underneath. Ideally what we try to achieve is a stone blanket with a gradual reduction in size that blends with the natural bed material (not economical).

The riprap blanket thickness should be at least 1 to 1.5 times the maximum stone diameter size or twice the average diameter size used. For dumped stone the maximum bank slope should be 1:2, while for hand placed stone it can be increased to 1:1.5.

Riprap has been used effectively in channel stabilization and realignment using the trench-fill technique shown in Figure 22. A trench is excavated at the base of the graded stream bank and is riprap filled with additional riprap placed on the bank above the trench. As the hydraulic flow of the stream erodes the bank between the stream and the trench, the bank fails and eventually the trench becomes the revetment.

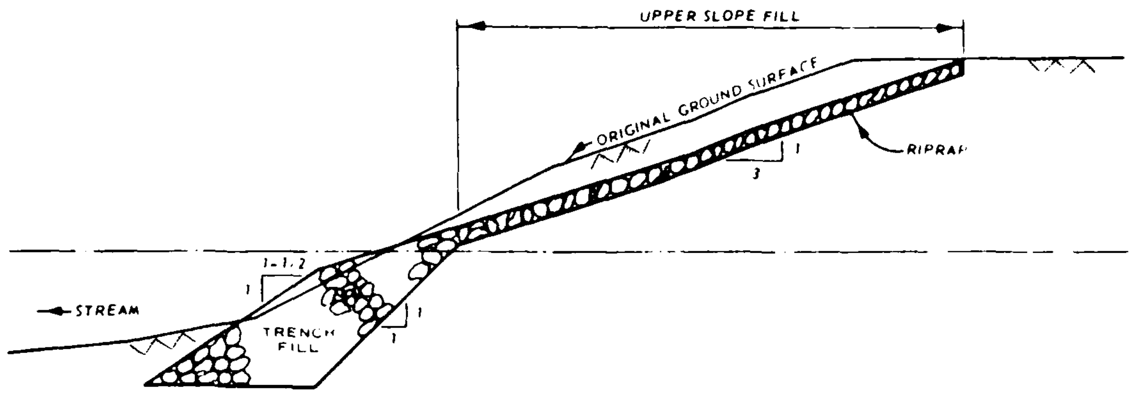

Figure 22. Trench-fill revetment (Source 2)

7.3 Gabions [25]

Gabions are prefabricated wire-mesh cages or baskets divided by diaphragms into cells. The wire-mesh is generally galvanized steel wire and can be coated if the gabion is to be used in a corrosive environment.

During the construction phase a gabion support apron is first laid on the stream bank that will extend a minimum of 6 feet past the toe of the gabion works. The gabion apron must have a height of 1.5 to 2 times the depth of the scour predicted at the stream system toe. Each apron cage is placed and securely wired together and then filled with stone. Next the gabion revetment cages are placed and wired securely to the apron and neighboring cages and then filled with stone. The stone should be slightly larger than the cage opening and offer maximum available density. As the cages are filled with stone the wires are also connected between opposite end walls to prevent bulging. The stone should also offer good to excellent resistance to weathering, freeze-thaw actions and abrasion.

Gabions are also flexible and can accommodate for minor changes in stream bank geometry. The stone filled cages also allow bank seepage to preclude excessive hydrostatic pressure failures of stream bank. Gravel and sand beds and filter cloths are sometimes used beneath the gabion structure to prevent migration of fines from the natural bank to the stream. Appendix A includes typical applications, installation, calculations and specifications by Maccaferri Gabions, Inc..

7.4 Articulated Concrete Mattresses [26]

Articulated concrete mattresses, because of their weight and flexibility, offers outstanding protection against stream bank erosion in areas subject to excessive hydraulic flow (more applicable to costal areas, but have been used on the larger navigable riverways). The only drawback is the specialized construction equipment required and the expense to install the revetment.

The basic unit is a slab of concrete 3 feet 10 1/4 inches long by 14 inches wide by 3 inches thick (can vary according to project size and span required). These slabs are cast and tied together by errosion-resistant reinforcement wire forming rectangular units measuring 4 feet wide by 25 feet long with a one inch spacing between slabs. This one inch articulated joint was further modified in the shape of a "V" which reduced the spacing from 10% of the total mattress down to 1%. This change further minimized stream bank materials from washing through the interstices preventing excessive settlement.

During the construction process, after the submerged stream bank has been shaped in preparation for mattress placement, the concrete mattress is assembled on a barge anchored over the submerged bank. When a 25 foot by 140 foot section is assembled it is termed a launch and subsequent launches are connected to each other until the desired length has been assembled. Next comes the actual placement of the launches. The first launch is secured to the bank and the barge starts to move toward midstream and the completed concrete mattress is moved off the barge and sunk inplace on the submerged bank. This process is shown in figure 23.

The actual shaping of subaqueous stream banks and concrete mat sinking operations are not commenced unless the river stage has fallen to 15 feet above mean low water. This essentially limits placing this type of revetment during the low water season. The upper limit of the concrete mattress should reach a height of about 6 foot above mean low water and should be laid to a point of about 50 feet past the stream system's thalweg. The articulated concrete mattress by ERO/CON Corporation is similar, but on a smaller scale and can be economically used for stream bank stabilization. This concrete block system is shown in Appendix B which includes typical applications, installation procedures, calculations and specifications.

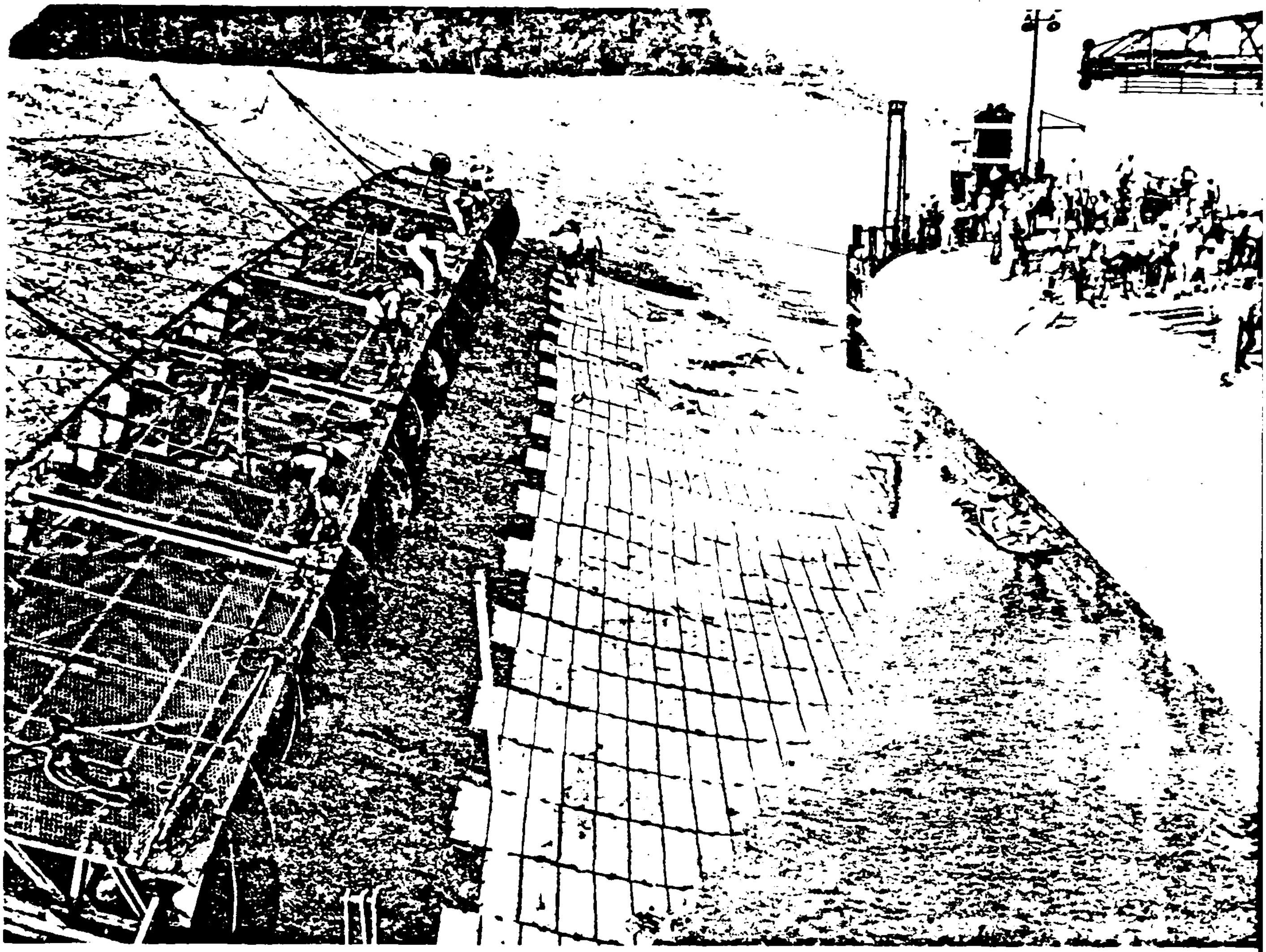

Figure 23. Articulated Concrete mattress being sunk from launching barge (Source 2)

7.5 Erosion-Control Matting [27]

There is a large variety of erosion-control matting available on the commercial market. This type of matting is generally installed by hand and does not require any specialized equipment. It is normally secured to the stream banks with stakes or staples, which can also be biodegradable.

The matting can come in various thicknesses and is normally structured in the form of a web, which allows vegetation to grow through the mat openings. This type of design can be either short or long term. Short term might involve the use of a biodegradable mat system which allows natural vegetation to grow through and stabilize the stream bank prior to decomposition of the mat system. A long term system could be in the form of a jumbled wire matting with a protective coating that allows natural vegetation to grow through, but remains in place for additional stream bank support.

7.6 Fences [28]

Fences can be used in a variety of ways to solve numerous stream bank protection problems on low-gradient streams with discharges less than 500,000 cubic feet per second (CFS). Fences can either be positioned parallel to the stream bank to be protected or transverse upstream or downstream. A typical parallel fence protection system on a gradual sloping bank might consist of two parallel fences along the stream bank 3 to 10 feet apart with brush, hay or rock stacked or dumped between the fences. This will provide an extra measure of protection against erosive action by the water currents. On steep banks one fence might be used in conjunction with the stream bank to hold the brush, hay or rock backfill in place. A parallel system is usually used as a stop gap measure to allow sufficient time for natural or planted vegetation to establish itself. On steep banks it is used to prevent sloughing. A transverse fence on the other hand is normally positioned to deflect or trap debris. A downstream orientation at an oblique angle to the current will deflect debris into the main channel. This type of fence is normally used to deflect large debris that might damage a bank and also to keep it clear. A transverse fence oriented upstream will collect and trap debris and is used to clear the main channel stream and serve to encourage sediment deposition.

All sorts of local materials can be used to construct stream bank protection fences. Fence posts can be treated or untreated wood, used rails, pipe steel beams, or concrete posts. The fence material is generally wood or wire, but rope and filter cloths have also been used. Design loading for the fence system is dependent on the water and debri loading of the stream system.

Fencing is not considered one of the more effective means of stream bank protection, but is commonly used especially in rural areas because no special materials or techniques are required for construction. Some typical fence systems are shown in figures 24 through 27.

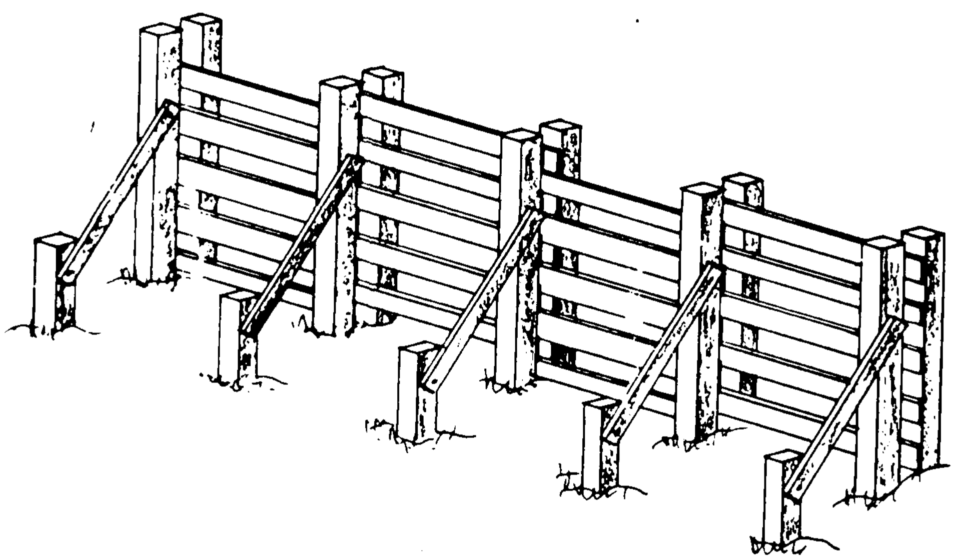

Figure 24. Wooden fence constructed parallel to bank (Source 4)

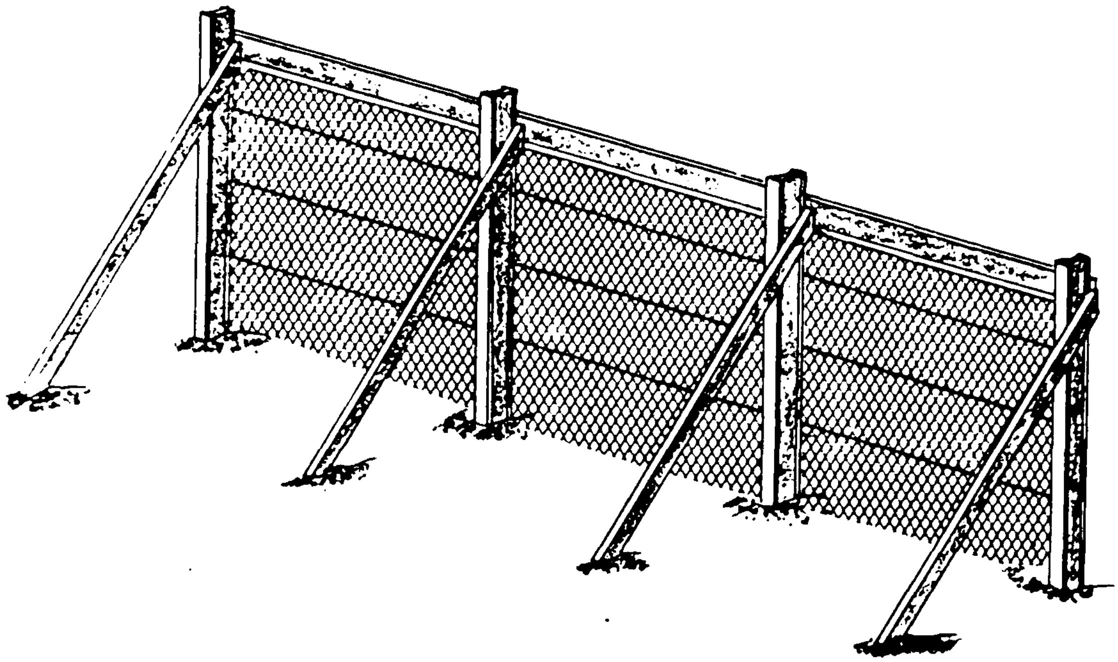

Figure 25. Single line of steel rail, wire-meshed fence as a retarder (Source 4)

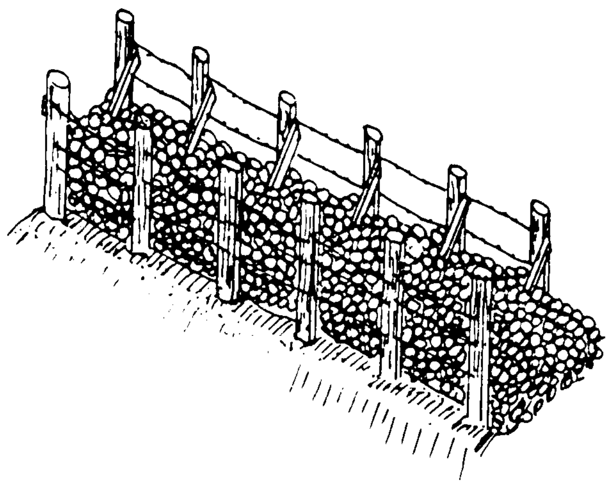

Figure 26. Double row fence of timber posts and barbed wire with rock fill (Source 4)

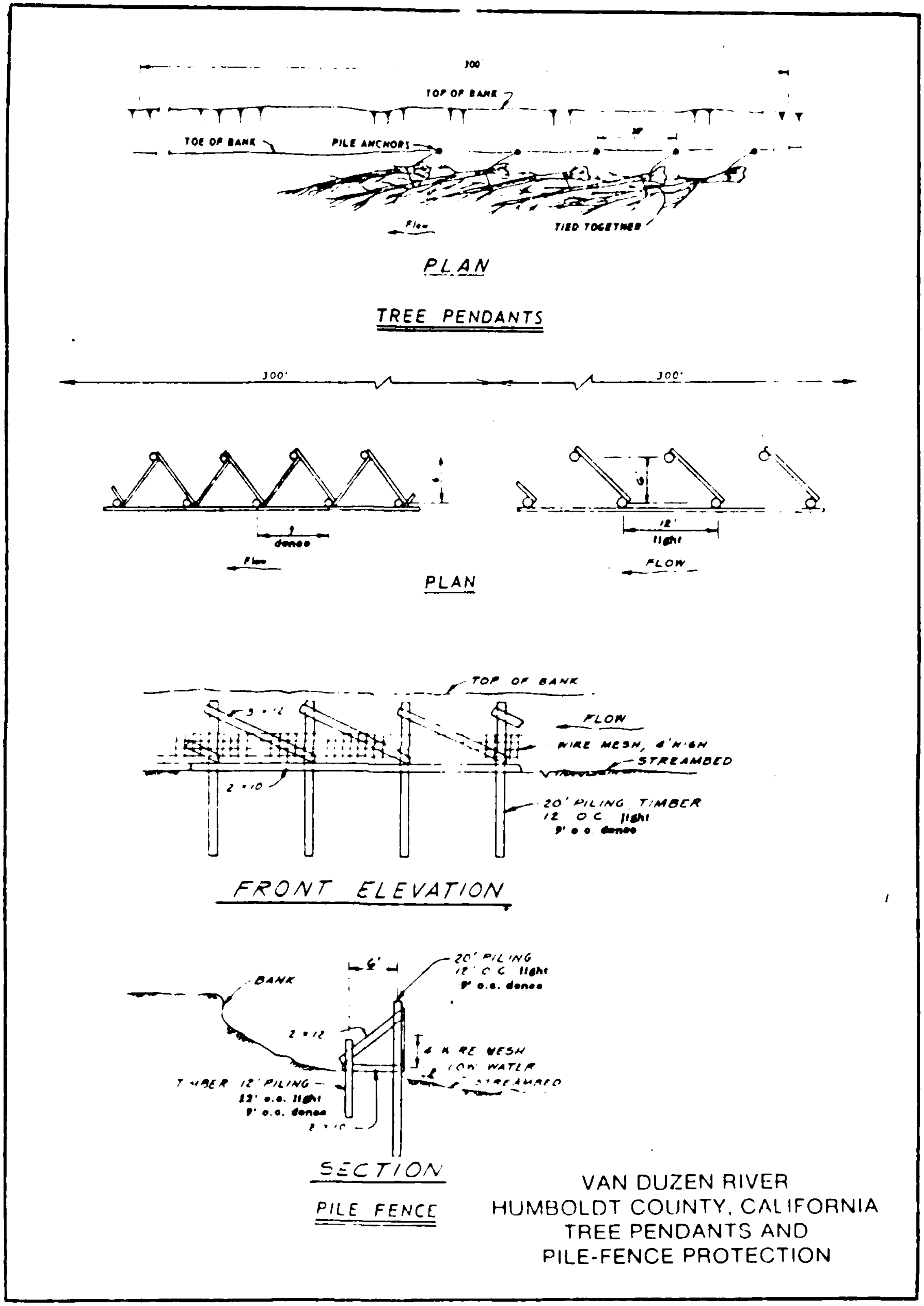

Figure 27. Pile fence system (Source 4)

7.7 Vegetation [29]

The major principal functions of stream bank protection measures are to keep fast moving water and transported coarse materials away from the sloped stream bank surface and to improve the structural integrity of the bank. In stream bank protection projects we can divide vegetative growth into grasses and woody plants. Grasses can establish themselves very quickly but offer less protection against periods of high velocity flow. Research in this area has also determined that the ability of grass to reduce stream system velocities is directly related to the length, width and density of the blade, the areal density of the grass and the depth of the root system. Stream velocities can be reduced by as much as 90 percent at the boundary layer between water and soil if the grass stand is well established.

The most important factor affecting the selection of a particular grass species to be used in a revetment project is the length of time required for the grass stand to establish itself on the slope. Selection is also based on soil and air temperature, total rainfall and rainfall distribution, type of soil available for planting, the bank slope and the ability of the soil to store water for plant growth during dry periods. Some grasses that have outstanding characteristics that provide optimum resistance to erosion often must be excluded from use in regions where the growing season is short or the stream banks are submerged for prolonged periods of time.

During construction the stream bank topsoil is stripped to eliminate weed growth that may tend to choke out the revetment grass to be planted. The exposed stream bank material is then sloped, rolled and finally scarified prior to planting. The grass can be planted by sodding, sprigging or more commonly by mechanical hydroseeding.

Woody plants have a greater initial cost/and a longer time to become established but are a more effective long-term protection measure. Stream bank sections with scouring problems can be stabilized by using woody plants at the bank toe and grass above the toe to minimize costs.

Above the mean high-water level on stream banks and in backwater areas, the major erosive soil action results in soil mass disintegration by alternate wetting and drying and wind. Grasses have proven themselves as excellent deterents to these erosive conditions.

Of all the bank protection methods, vegetation is the only natural self-renewing method and in most cases the most economical and aesthetically pleasing.

7.8 Jacks [30]

Jacks consist of three linear members that are bolted or welded at their midpoint so that they resemble a perpendicular toy jack. Jacks can be made of wood, steel and concrete materials. During construction the jacks are assembled and laced with cable. Then they are placed in a linear array and connected at 15-30 foot intervals with additional cables. Jack arrays can be parallel or at an angle with the stream flow. Parallel systems are called diversion lines and angled systems are called retard lines. The most commercially used jack system is called the Kellner Jack Field. The array consists of retard lines anchored to the stream bank with deadmen that extend into the channel where the free end is anchored to a diversion line.

The Kellner Jack Field is an indirect stream bank protection system (not in contact with the banks) and is used to control the stream system's thalweg. Moving the thalweg away from the stream bank tends to scour the main channel and improve navigation, while protecting the stream banks.

The Kellner Jack Field is also extremely flexible and can conform to changing channel geometry. This type of stream protection is more applicable to wide, shallow, silt-laden streams subject to severe scour during high-velocity flows. Flows can be reduced from peaks up to 5 fps down to 0.5-0.25 fps by an effective Kellner Jack Field. A correctly designed and installed system can build banks, remove debris from the main channel, eliminate sedimentation in the main channel and allow natural or planted vegetation to grow and provide additional stream bank protection.

Although jack fields are not aesthetically harmonious with flood plain landscaping, they have proven to be effective in locations where riprap and other more economical types of revetment are not available. Jack fields are not recommended for use in areas with corrosive environments, stream systems that experience extremely high velocity flows or on stream systems where the stream bank to be protected is higher than the jack field. Figure 28 shows a Kellner jack field parallel to the stream bank.

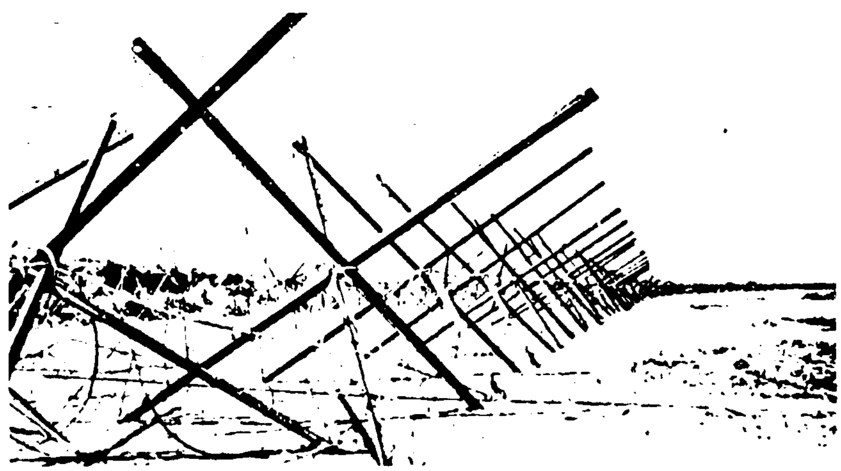

Figure 28. Kellner jack field (Source 2)

7.9 Bulkheads [31]

This type of revetment is used to protect stream banks that are steep and unstable, to improve water transportation from bank to bank, or to create additional water front by backfilling behind the bulkhead. Bulkheads are generally constructed out of timber, steel or concrete, with timber being the least costly. Prefabricated asbestos fiber bulkheads are also available from commercial sources.

Commercial bulkhead sheets are generally worked into the soil with a compressed air jet or driven into the ground with a mechanical aid. The sheets are then joined together and capped. The required specialized equipment and procedures for this revetment are extremely costly.

7.10 Concrete Pavement [32]

Concrete pavements used for bank protection are generally expensive because of form work, mix design, batching, placement and curing that must be rigidly controlled. A rigid concrete pavement does provide a high degree of reliability over a long life with minimum maintenance, if scour under the slab due to inadequate subsurface drainage can be prevented. Concrete pavements are normally used along stream banks, bridge abutments and main-line levees in heavily populated and/or industrial areas.

7.11 Transverse Dikes [33]

Transverse dikes are used to deflect eroding river currents away from stream banks and/or reduce stream flow velocities. Transverse dikes are an indirect method of protection since the actual revetment is not placed directly on the stream bank to isolate the erosion envelope.

The two principal types of transverse dikes are permeable and impermeable. Permeable transverse dikes retard flow and cause deposition of sediment while impermeable transverse dikes redirect flow to the main channel. In either case the stream system geometry is altered and must adjust to regain the cross-sectional area required to pass the same discharge as before the dike was constructed. As the stream bank being protected begins to stabilize the main-channel flow begins to scour out its bed until original flow stabilization is reached.

Timber piles are the most common type of permeable dike and can be designed and constructed using face boards with horizontal bracing, as well as single piles and clusters (3 piles strapped together) in single or multiple rows. Design selection is dependent on stream depth and hydraulic flow conditions that must be sustained by the dike. Design of pile spacing is also dependent on the quantity and characteristics of the sediment being transported. Suspending screens can also be used to encourage more effective deposition (applicable to fine sediment being transported). A transverse stone dike is the most common impermeable dike and is usually constructed from quarry-run stone with specific limitations on maximum size and amount of fines.

These dikes are constructed with crowns varying up to 10 feet or more depending on the stream reach's hydraulic conditions. The principal advantage of an impermeable stone dike is that the void volume can be minimized passing little or no water through. The result is sedimentation between dikes and reduced scalloping between dikes that might be caused by eddies and over topping flow.

The primary purpose of a transverse dike is to move the thalweg further away from the stream bank. To accomplish this, the transverse dike must extend into the stream past the point where the highest velocities occur, but not interfere with industrial or recreational navigation.

Design spacing between any two dikes is generally the average of their lengths multiplied by a spacing-length ratio (based on design experience).

Selection of this type of revetment is limited by local cost effectiveness and stream usage. Some typical wood pile dikes are shown in figure 29.

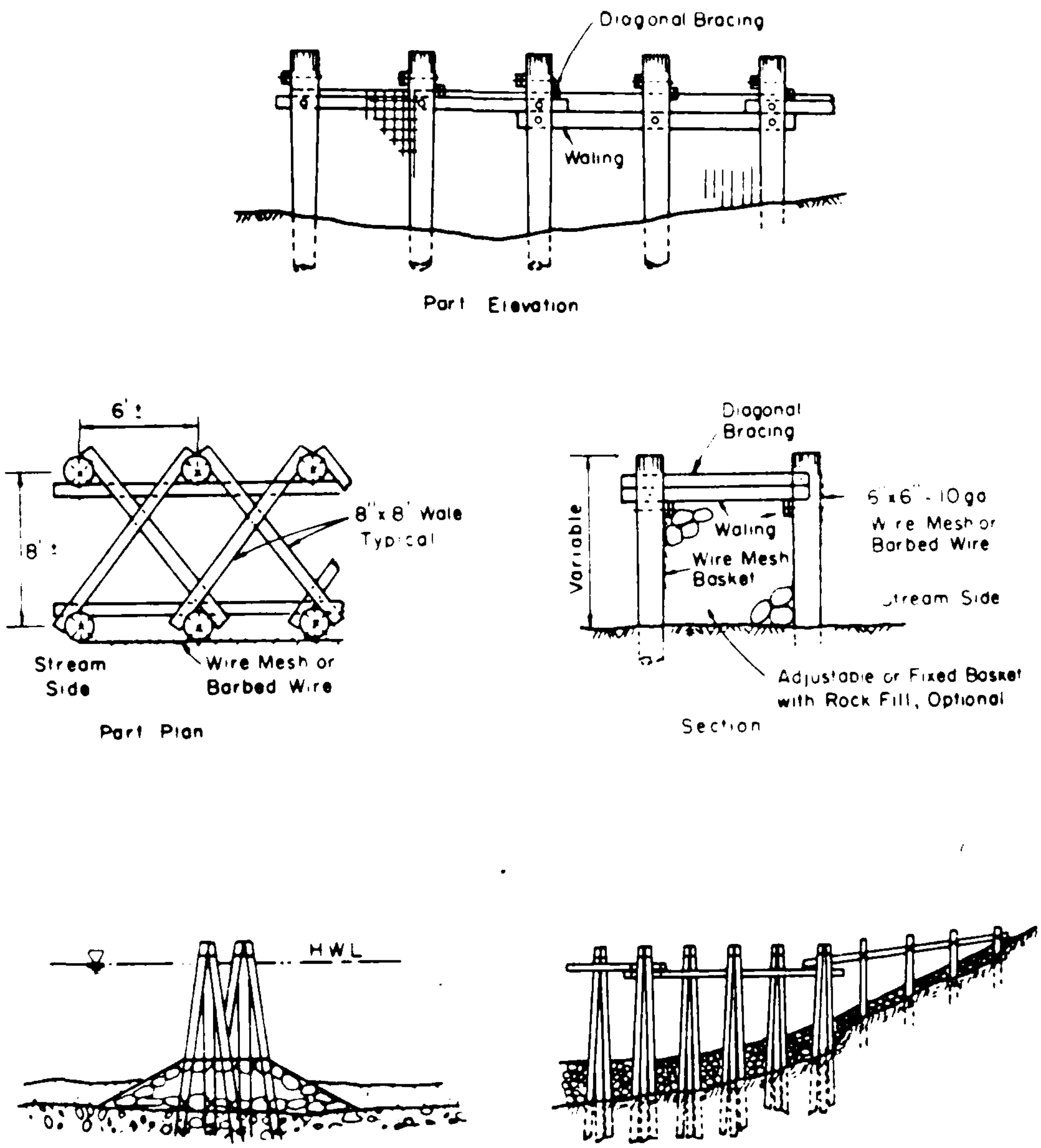

Figure 29. Timber pile dikes (Source 4)

7.12 Woven Plastic Filter Cloths [34]

The use of filter cloth over the past 25-30 years has been an exceptable method of stream bank protection in conjunction with concrete blocks, riprap, vegetative growth, dikes, walls, mats and other traditional revetment methods. One of the primary causes of stream bank erosion is due to an inadequate filtration system in which the fine soil particles are removed from the stream bank resulting in subsequent erosion or bank failure. Normally, filters of granular soils are used in layers of graded sands, gravels and stone materials in various thicknesses to provide the required protection. All too often these materials are not readily available or are too expensive due to hauling and placing requirements. The placement of these materials is usually tedious and demands strict supervision.

Once the natural stream bank characteristics are known, a woven filter cloth can be selected for use as a filter and/or structural support blanket. The cloth selected should allow the water to pass freely while preventing the stream bank's fine soil particles from passing.

During the construction phase, the stream bank is cleared and graded to the appropriate slope to accept the filter cloth. The cloth is then laid and anchored with wood or metal stakes. Where the filter cloth sheets meet you can use a staked 2 foot overlay, with a sewn or stapled seam. All man-made penetrations and tears during the construction phase must be sealed to preserve the filter cloth's integrity. The revetment to be placed on top of the filter cloth should use a controlled drop height not to exceed 2 to 3 feet above the filter cloth to prevent puncturing by other materials to be layered. Revetment and filter cloth seams should also be offset.

Construction techniques for placement of the actual revetment on top of the filter cloth should not vary from the normal sequences mentioned in previous sections of this report. Appendix C includes information on applications, handling and installation, calculations and specifications.

CHAPTER EIGHT

GENERAL REVETMENT DESCRIPTION AND RELATIVE COST

8.1 General [35]

Stream bank protection systems can be subdivided into two categories, which are flow redirection structures and stream bank revetment structures. Sections 8.2 and 8.3 provide unit cost per foot for each type of stream bank protection. These unit costs also include engineering and design (E&D) and supervision and administration (S&A) as well as actual construction costs. These costs are based on information collected by the U.S. Army Corps of Engineers from both the public and private sectors.

8.2 Flow Redirection Structures [36]

Flow Redirection Structures are indirect methods of stream bank protection, since the actual revetment is not placed directly on the stream bank. Flow redirection structures can be further broken down into two types, ones that are perpendicular or at an angle to the stream bank and parallel to and offset from the stream bank. These two groups are presented below with their relative costs.

Flow Redirection Structures Perpendicular to or at an angle to the stream bank	Cost Ranges $/ft of Bank Protected
- Sand dike with gravel core and cover, vegetated	45
- Rock hard points, at various spacings, into the river or in the bank	31-177
- Gabion groins (dikes)- wire baskets filled with stone and gravel	119
- Permeable timber fence or wire fence dikes at various spacings with pile supports	147
- Concrete pile hard points-concrete piles formed together in the banks with a concrete cap	1152
- Nylon sand-filled bag groins (dikes)	132
- Longard tube groins (dikes)-48" diameter nylon tubes of various lengths filled with sand	72
- Tree pendants-dead trees from along the stream, dragged and placed in front of the eroding banks and anchored to the bank	93

Flow Redirection Structures Parallel to and offset from the stream bank	Cost Ranges $/ft of Bank Protected
- Permeable timber or wire mesh fence, pile supported with and without brush backfill to bank	28-437

- Tree pendants-dead trees from along the stream, dragged and placed in front of the eroding banks and anchored to the bank — 19-24
- Floating tire breakwater-used tires filled with buoyant material and tied together to form a wave breakwater — 346
- Kellner jacks-steel angles bolted together at the midpoint in a shape like a jack and wired together in the stream, parallel to the shore — 109

8.3 Stream Bank Revetment Structures [37]

Stream bank revetment structures are forms of bank protection which are directly applied to the stream bank for protection. This group is presented below with their relative costs.

Stream Bank Revetment Structures	Cost Ranges $/ft of Bank Protected
- Rock-fill toe with various inexpensive, upper-bank protective systems and vegetation	83-665
- Rock-fill stability berm to correct a bank instability problem with various upper-bank protection systems	142-209
- Wood and wire fence anchored to the bank	32
- Gabion dike at toe of slope and backfilled to the slope	659

- Stone-fill dike at toe of slope and backfilled to the slope with and without upper-bank protection	150-576
- Windrow trenches- trenches at the top of bank in which stones are placed at varying rates to fall down the slope as erosion of bank occurs	44-149
- Gabion mattress-interlaced wire mesh baskets filled with river cobbles or crushed rock, with and without filter fabric underlayment and upper-bank vegetation	137-270
- Used tire mattress with earth or stone fill; with and without filter fabric underlayment; upper bank vegetated	78-874
- Sand and sand-cement filled bags with filter *fabric underlayment and upper bank vegetation*	74-145
- Baled hay with and without filter fabric underlayment; upper bank vegetated	159-210
- Precast cellular concrete mattress with filter fabric underlayment and upper-bank vegetation	83-603
- Used tire wall with and without filter fabric; upper bank vegetated	159-210
- Used tire wall, pile-supported, with or without filter fabric	223
- Soil-cement blanket-a mixture of the natural soil and cement compacted in place	467-823
- Grout-filled mats (e.g., Fabriform)	197-828

- Concrete and log crib walls-an interlacing of concrete beams or logs forming a box and backfilled	800
- Filter fabric matting anchored at toe and top of bank, and randomly between on the slope	70
- Enkamat-a patented product to promote vegetative growth	101-111
- Dumped rubble-coarse concrete and brick material from building debris	180-400
- Riprap blanket-Corps criteria and quarry-run stone	64-298
- Wire-mesh-lined, log cribs filled with river cobbles	285
- Vegetated slope only	64

CHAPTER NINE

NEW ENGLAND DEMONSTRATION PROJECT [39]

9.1 General

The New England Division of the U.S. Army Corps of Engineers under the authority of Public Law 93-251, Section 32 has selected both Haverhill, N.H. and Northfield, Ma. as stream bank demonstration sites. The final selection of these two sites was based on the cooperation of the landowners, communities, states and representative nature of the many miles of stream bank erosion along the Connecticut River. The Haverhill, N.H. site will be discussed in the sections to follow.

9.2 Erosion Problem

The haverhill, N.H. demonstration site is approximately one mile downstream from the Newbury-Haverhill bridge and is shown in figure 30. The left bank of the river which is actively eroding at the rate of 10 feet per year ranges in height from 5 to 22 feet above the normal water

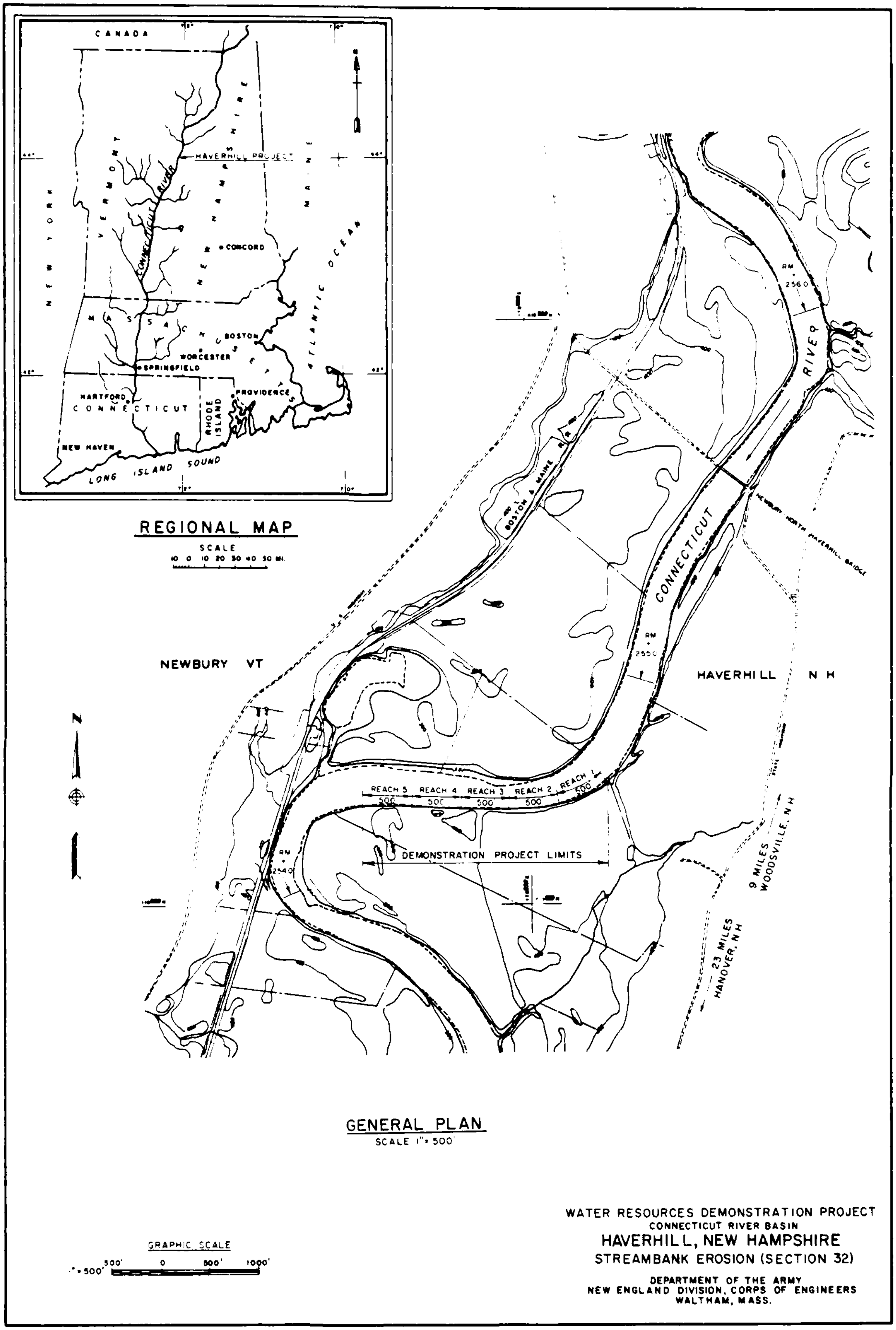

Figure 30. Site location (Source 39)

level. This site is also located 38 miles upstream from the Wilder Dam (hydroelectric plant). Although the dam operation varies the water level at the demonstration site by 1 to 1.5 feet, this stream section is influenced mainly by conditions typical of a natural flowing, meandering river. Annual spring runoff due to storms and snow melt inundates the lower bank and in cases of unusually high spring runoff and flood flows the whole bank is inundated. Erosion at the site is caused by shear and eddy forces acting on the outside of the meandering river bend. Ice also contributes greatly to the erosion process during the winter season. The land being lost is farmland with the likelihood that an oxbow of 30 acres would be created if the current erosion process is allowed to continue.

9.3 current and Historical Data

The population of Haverhill is approximately 2500 and the labor force consists of people engaged in manufacturing, light industry, agriculture and tourist trade.

Flow conditions at the Haverhill site are best represented by the U.S. Geological Survey flow gage located 11 miles upstream. The average summertime low flow of 3450 cfs occurs during July through October and the average snow melt low flow of 15635 cfs occurs during April and May. The average annual peak flow discharge has been 33100 cfs since the completion of the last major upstream storage project in 1961. Figures 31 through 33 represent this information.

The soil conditions at the site were determined by using data collected and soil test results from 4 borings taken along the bank line 30 to 40 feet landward. Analysis of the soil test results indicate that the bank materials were water-laid deposits composed mostly of silty fine sand (SM) and fine sandy silt (ML). The soil classification and test results are shown in figures 34 through 36. Most of the river bank was eroded to an almost vertical bank with little to no vegetative covering.

The main types of erosion that have been observed in their order of importance at this site are sloughing, undercutting and mass wasting, and the principal cause is shear stress associated with high stream flow. The shear force is further magnified at this site since it is located on the outside of a sharp stream bend. Pool fluctuation, seepage, boat waves and overbank drainage have a much less affect on the overall erosion process.

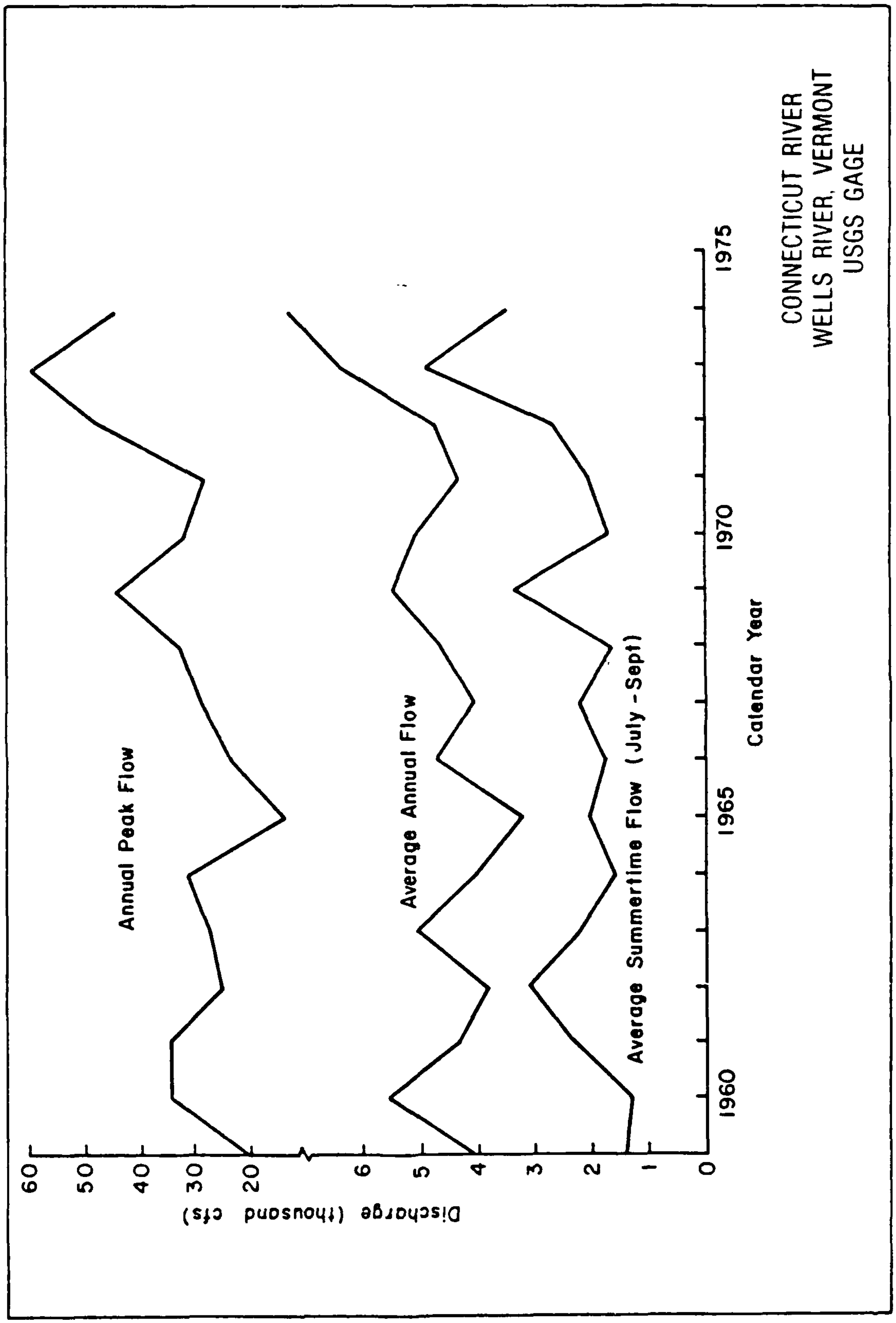

Figure 31. 15 year discharge curves (Source 39)

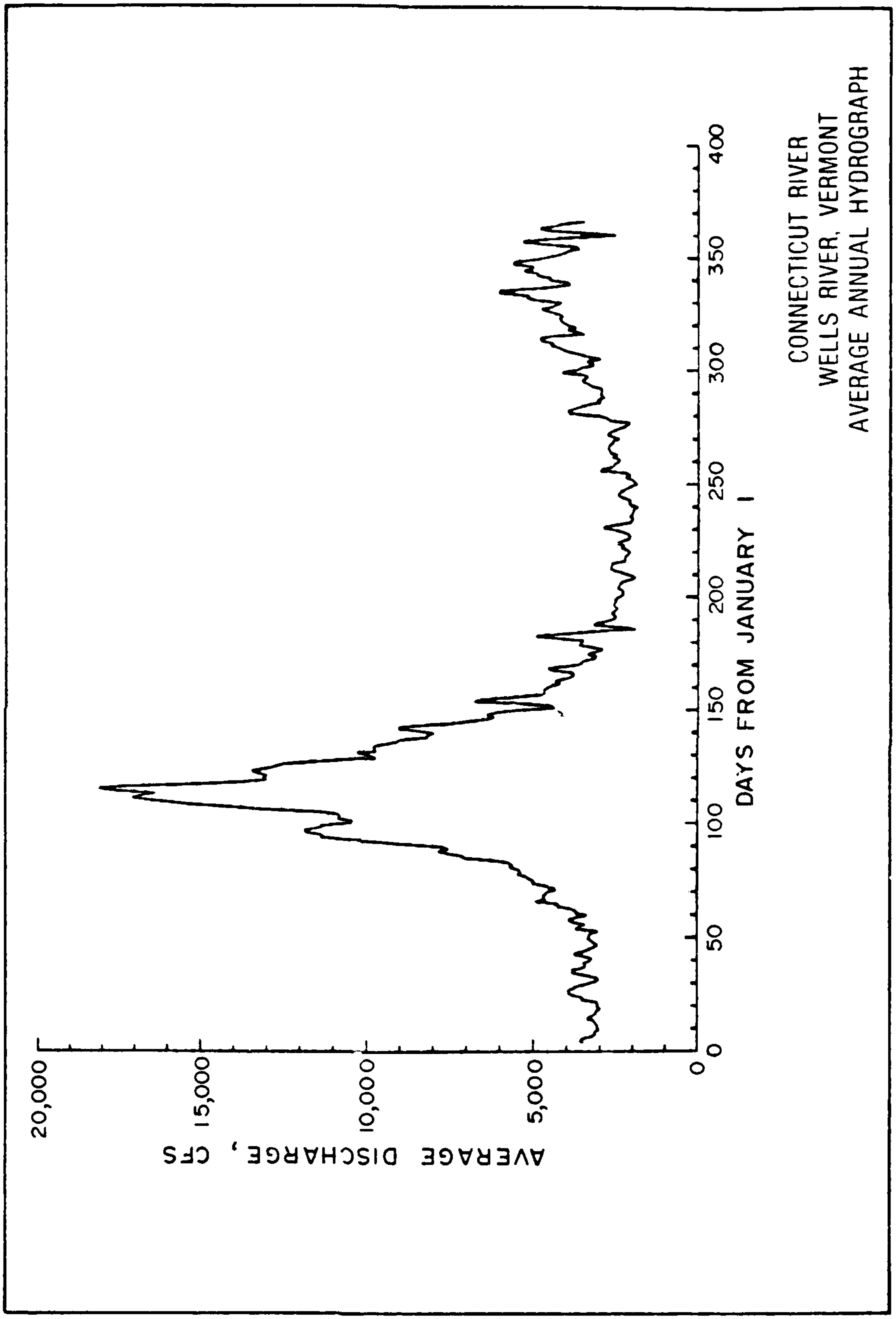

Figure 32. Average annual discharge (Source 39)

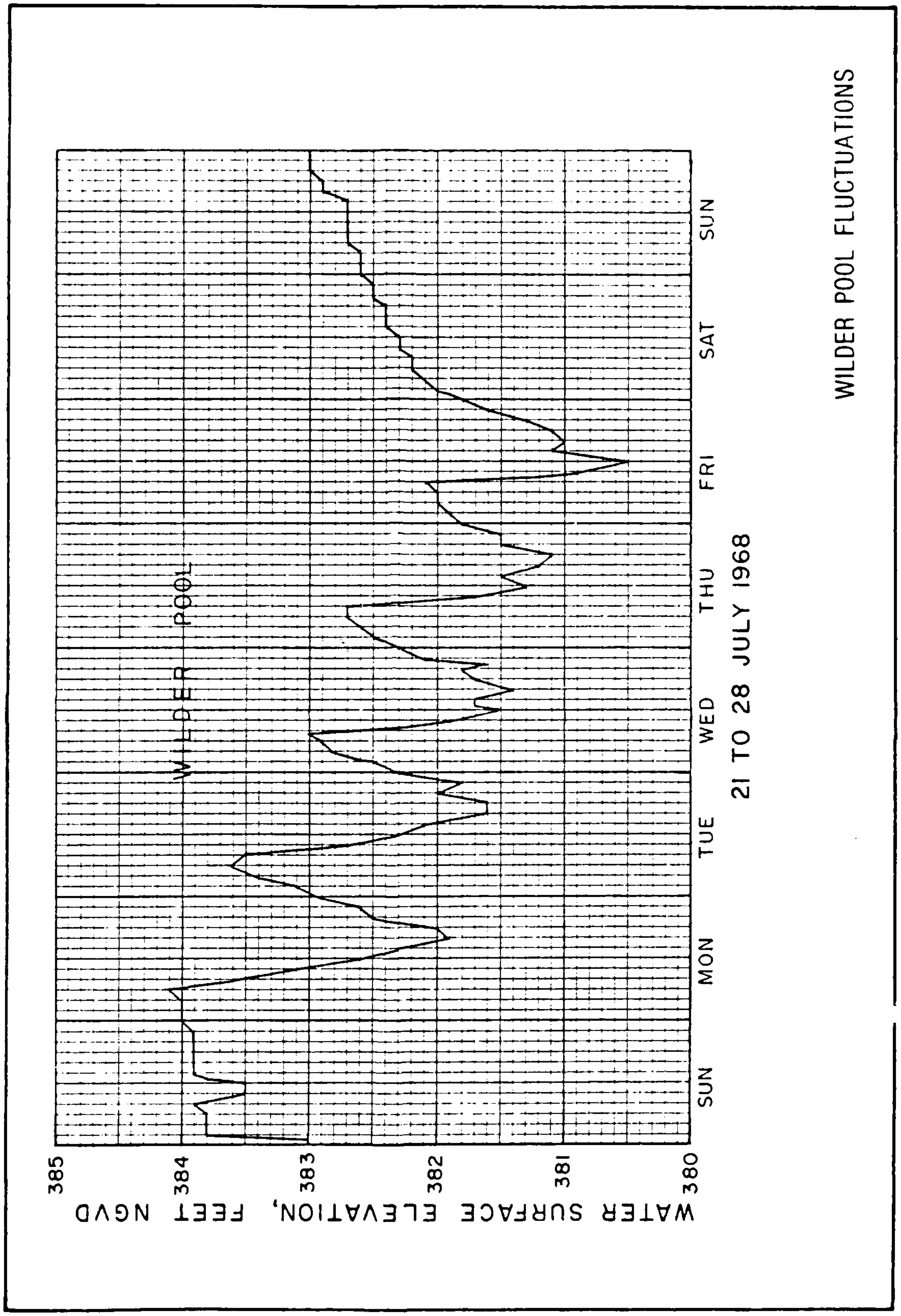

Figure 33. Wilder pool fluctuations (Source 39)

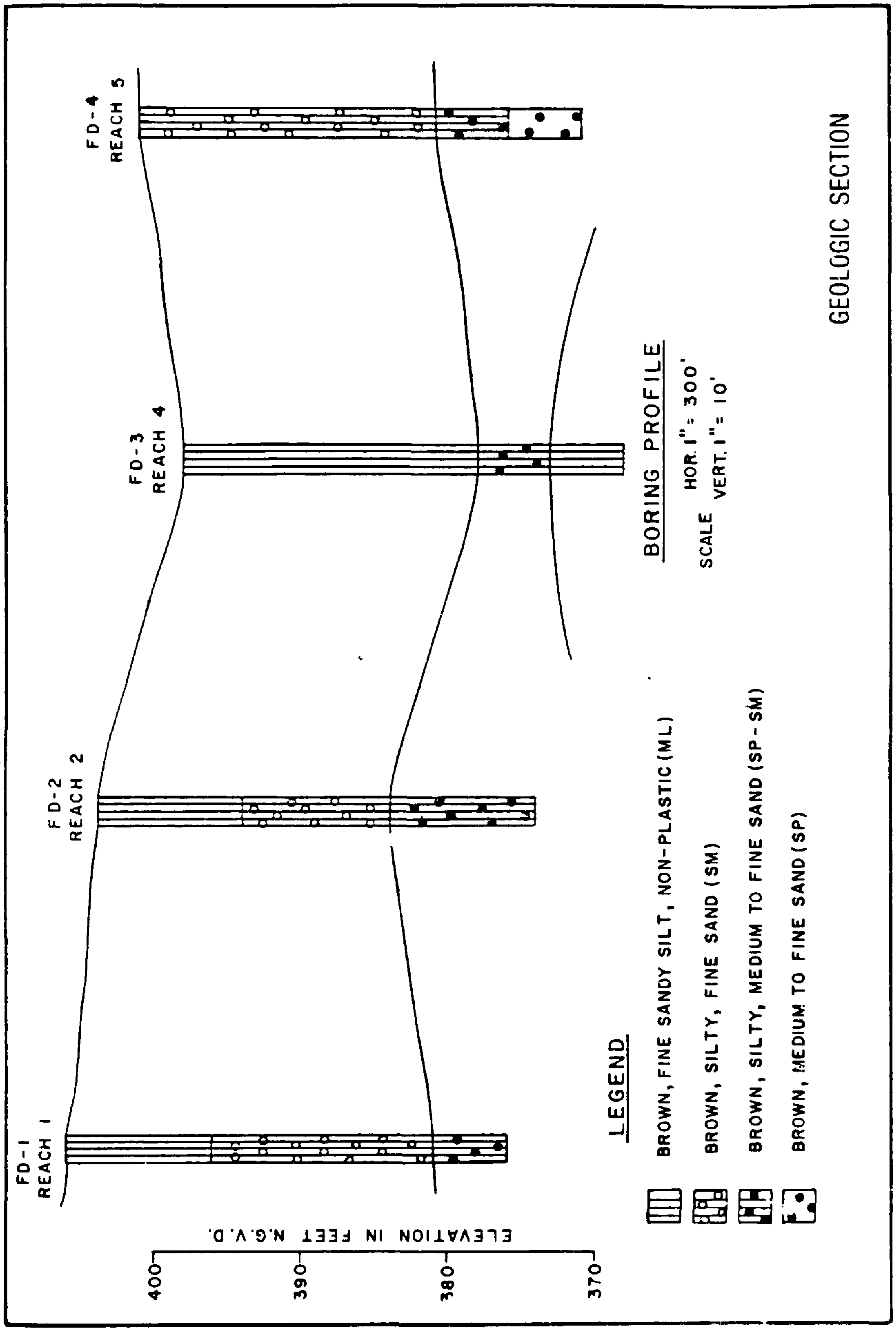

Figure 34. Geologic section (Source 39)

AD-A185 553 STREAMBANK PROTECTION AND EROSION CONTROL(U) FLORIDA UNIV GAINESVILLE J AMARANTIDES 1987 2/2

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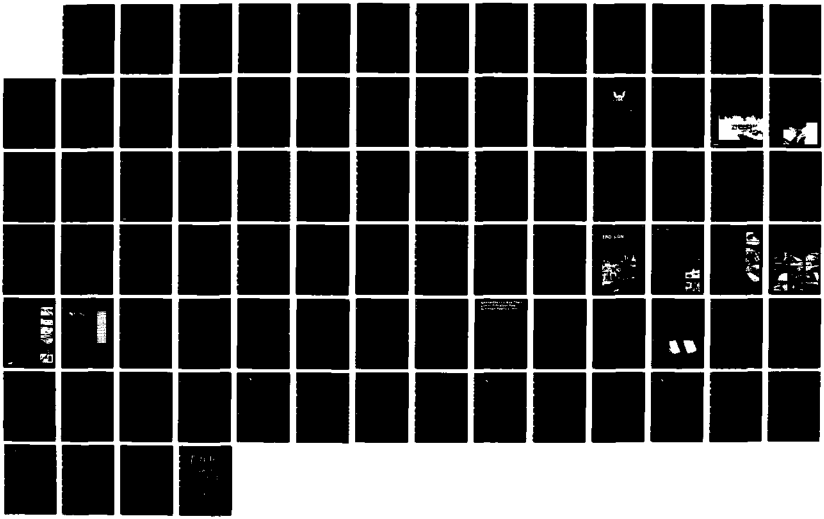

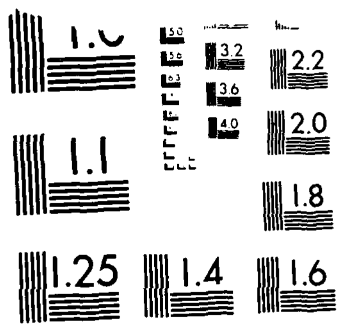

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

REACH NO.	EXPL. NO.	TOP ELEV. FT.	SAMPLE NO.	DEPTH FT.	SOIL SYMBOL	MECHANICAL ANALYSIS GRAVEL %	SAND %	FINES %	D_{10} mm.	ATT. LIMITS LL	PL	SPECIFIC GRAVITY	NAT. WATER CONTENT % DRY WT TOTAL	-NO4
1	FD-1	406±	J-1	0.0- 5.0	ML	0	32	68	0.015	NP	NP	2.73	16.9	16.9
			J-3	10.0-15.0	SM	0	67	33	0.035	NP	NP	2.68	11.4	11.4
			J-6	25.0-30.0	SP-SM	3	89	8	0.10	NP	NP	2.71	16.3	-
2	FD-2	404±	J-1	0.0- 1.5	ML	0	20	80	0.0066	34	29	2.68	27.0	27.0
			J-3	11.5-15.0	SM	0	58	42	0.026	NP	NP	2.65	10.3	10.3
			J-6	26.5-30.0	SP-SM	0	94	6	0.10	NP	NP	2.70	21.9	21.9
4	FD-3	398±	J-1	0.0- 5.0	ML	0	38	62	0.018	NP	NP	2.68	16.6	16.6
			J-3	10.0-15.0	ML	0	25	75	0.012	NP	NP	2.72	34.0	34.0
			J-5	20.0-25.0	SP-SM	3	89	8	0.080	NP	NP	2.68	21.6	-
			J-6	25.0-30.0	ML	0	5	95	0.014	NP	NP	2.71	27.5	27.5
5	FD-4	401±	J-1	0.0- 1.5	SM	0	76	24	0.040	NP	NP	2.68	13.5	13.5
			J-4	15.0-16.5	SM	0	78	22	0.040	NP	NP	2.69	29.6	29.6
			J-6	25.0-26.5	SP	0	96	4	0.15	NP	NP	2.69	25.7	25.7

SOIL CLASSIFICATION DATA

Figure 35. Soil classification data (Source 39)

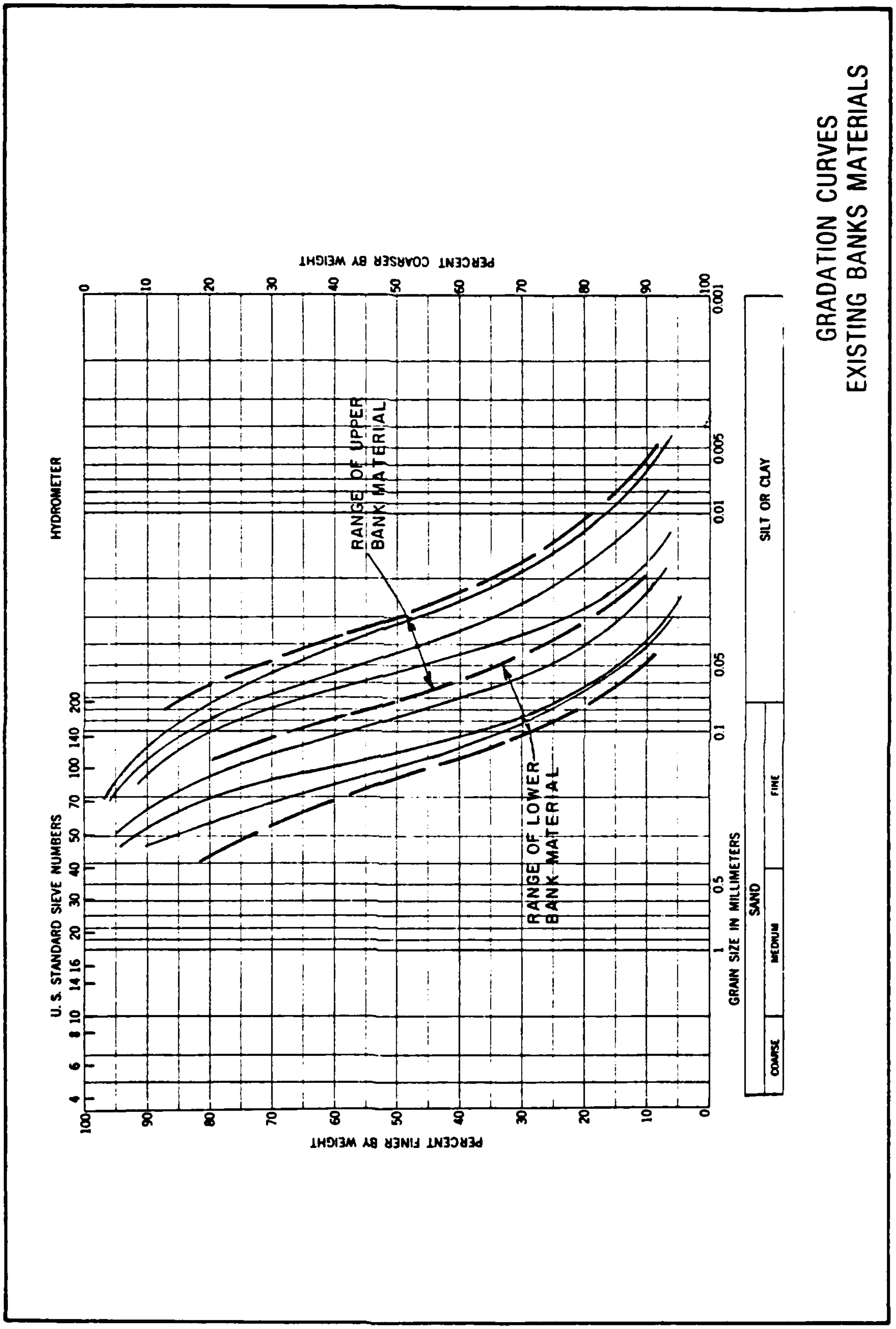

Figure 36. Soil gradation curves (Source 39)

9.4 Design and Construction

The primary driving force in selecting revetment types for this site was to gain experience with new and innovative methods of stream bank erosion control, while also using locally available materials and simplistic construction techniques that the local work force could perform with their available assets.

The demonstration site is 2500 feet long and consists of 5 revetment reaches each 500 feet long. The stream bank revetment is further divided into upper and lower sections, where the upper bank revetment in all 5 reaches is some form of vegetative growth. The lower bank revetments are described below;

1. A 12 inch thick gabion mattress will be placed from the underwater toe to a point 3 foot vertical above the normal water line. Filter fabric will be used on one half of this reach. The bank above will be dressed to its natural slope (1 on 1.5) and seeded.

2. A matting of interlocked rubber tires will be placed on the underwater slope from the toe to a point 3 feet vertical above

the normal water surface. The tires in half this reach will be filled with rock and the other half with earth. The bank above will be dressed to its natural slope (1 on 1.5) and seeded.

3. The sand-cement paper rip-rap bags will be placed on the underwater slope from the toe to a point 3 feet vertical above the normal water surface. Filter fabric will be used on one half of this reach. The upper bank will be formed to a 1 on 2 slope and seeded.

4. The underwater bank will be reformed to a 1 on 2 slope and overlaid with baled hay which is contained by wire mesh. The upper bank will also be formed to a 1 on 2 slope and seeded.

5. The final section will remain in its present condition below the water line. The upper bank will be formed to a 1 on 2 slope and seeded.

The 5 reaches are shown in figures 37 through 39.

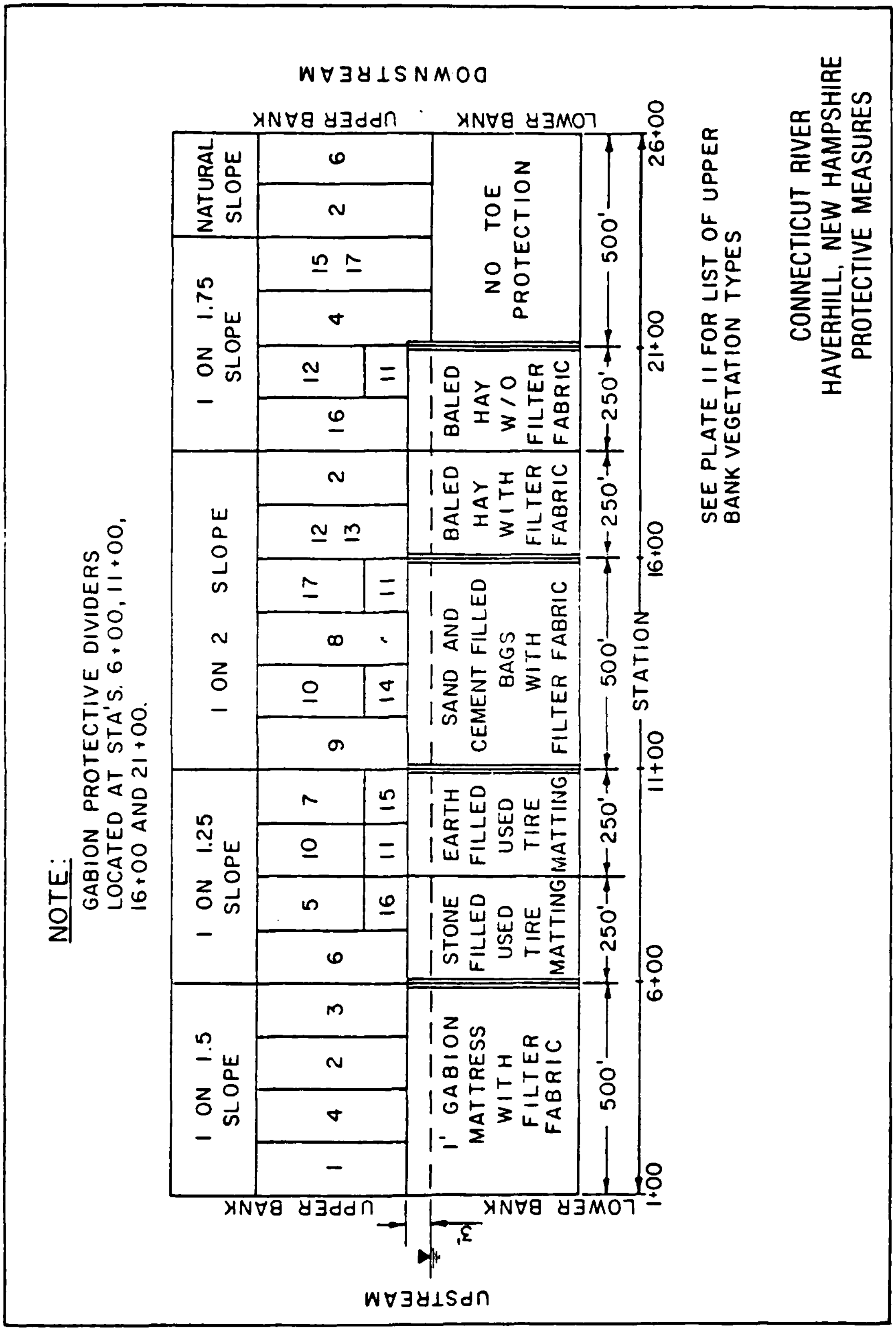

Figure 37. Plan view of revetment types (Source 39)

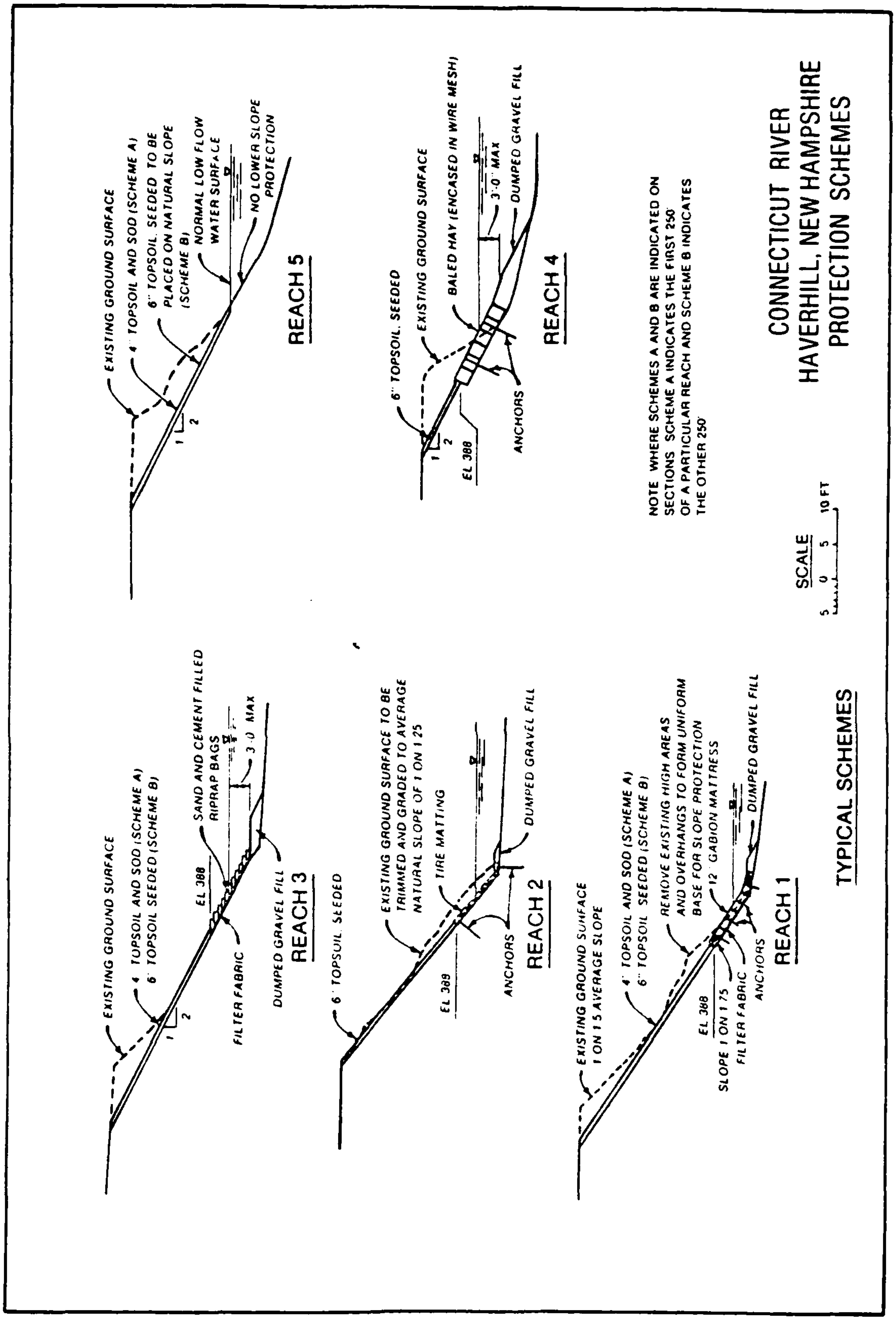

Figure 38. Cross section view of revetment types (Source 39)

SEED MIXTURES

1 REED CANARYGRASS
KENTUCKY 31 FESCUE
REDTOP

2 REED CANARYGRASS
CREEPING RED FESCUE
REDTOP

3 REED CANARYGRASS
KENTUCKY 31 FESCUE
BIRDSFOOT TREFOIL

4 CROWNVETCH
KENTUCKY 31 FESCUE
CREEPING RED FESCUE

5 FLAT PEA
KENTUCKY 31 FESCUE

6 CROWNVETCH
FLAT PEA
KENTUCKY 31 FESCUE

7 BIRDSFOOT TREFOIL
CREEPING RED FESCUE

8 CREEPING RED FESCUE
BIRDSFOOT TREFOIL
REDTOP

9 KENTUCKY 31 FESCUE
CREEPING FESCUE
REED CANARYGRASS
REDTOP

10 KENTUCKY 31 FESCUE
CREEPING RED FESCUE
REDTOP

SHRUBS AND VINES

11 PURPLEOSIER WILLOW

12 SIBERIAN DOGWOOD

13 REDOSIER DOGWOOD

14 SUMMERSWEET

15 AMERICAN BITTERSWEET

16 VIRGINIA CREEPER

17 HALL'S HONEYSUCKLE

NOTE: NUMBERS ARE KEYED TO PANELS ON PLATE 10

UPPER BANK VEGETATION
HAVERHILL DEMONSTRATION PROJECT

Figure 39. Upper bank vegetation types (Source 39)

9.5 Monitoring

Cross-section surveys were taken one year before and just prior to construction, with one additional survey of reach 5 that failed. Settlement monuments were periodically checked with no significant change. As of December 1986 no significant floods have occurred and the Connecticut River has not reached bankfull conditions. The monitoring program is summarized in figure 40.

The U.S. Geological Survey has provided velocity readings for the site visits for low, moderate and high flow conditions and are shown in figure 41.

9.6 EVALUATION

The maximum discharge during the evaluation period was estimated at 19400 cfs, which is much lower than the mean annual flood of 33100 cfs. The lower bank was over topped by approximately 3 feet during this flow period. In the vegetated upper bank, minor scouring was observed in the over topping zone of reaches 1 through 4. The upper bank also experienced minor gully erosion due to concentrated surface runoff. Although the vegetation is well established no evaluation can be made since no significant river flows have occurred after project completion.

Reach 5 suffered a major failure due to no toe revetment used on the lower bank. The earth filled rubber tire revetment, reach 2B, experienced minor settlement due to the loss of earth filling in the tires. Minor bulging and voids were also observed in the baled hay revetment. The sand-cement filled bags, reach 3, have deteriorated as intended, but the sand-cement is also eroding. The gabion and stone filled rubber tires were found in good condition.

9.7 Conclusion

Although no high flow conditions have been experienced at this site as of December 1986, toe protection is an essential part of any successful revetment project. This is supported by the failure in reach 5. Stone fill vice earth fill should be used in the tire revetment as demonstrated by the superior performance of reach 2A over 2B. Noncorrodable banding should also be used with rubber tire revetment. Some form of structural matting should be added to the upper vegetated bank to prevent gullies and mulching and wood chips used on a 2:1 bank slope are not reliable and are washed away by water movement.

FIELD DATA OF PHYSICAL FEATURES	FREQUENCY
1. Detailed topographic survey of bankline from thalwag to 15 feet beyond top of bank.	Taken the year before and just prior to construction.
2. Cross sections of bankline extending from thalwag to 15 feet beyond top of bank.	Developed for project design and taken as needed for repair and reconstruction work.
3. Settlement monuments checked for vertical and horizontal movements.	Checked just after construction and then on as needed basis.
4. Velocity measurements at toe of slope and 40 feet riverward and recording of discharge and water surface elevation.	Taken during low, medium, and higher flow periods.
VISUAL OBSERVATIONS	
1. Aggradation-degradation processes.	Semi-annually for all visual observations.
2. Erosion and river conditions.	
3. Changes in aquatic and terrestrial habitat.	
4. Changes in upper slope vegetation.	
5. Changes in structure integrity and material durability.	
6. Surface current flow patterns.	
MATERIAL TESTS	
1. Borings of bank material.	Once during preconstruction period.
2. Mechanical analysis of riverbank material.	
3. Classification of bank material.	
4. Specific gravity, Atterberg limits, hydrometers and water content of bank material.	
5. Analysis of construction materials when appropriate.	As needed during construction.
PHOTOGRAPHY	
1. Aerial photography	Preconstruction photos taken at site.
2. Ground level periodic photographs taken at predetermined locations.	Taken semi-annually beginning at the completion of construction.

CONNECTICUT RIVER
HAVERHILL DEMONSTRATION SITE
MONITORING PROGRAM

Figure 40. Monitoring Program (Source 39)

	Visit #1				Visit #2				Visit #3			
Date:	4 Dec 79				4 Apr 80				15 Apr 80			
Water Surface Elevation (Ft. NGVD):	383.5				385.0				390.1			
Estimated Discharge (cfs):	2,400				2,700				13,400			
	At Toe		40 Ft. From Toe		At Toe		40 Ft. From Toe		At Toe		40 Ft. From Toe	
Reach	Depth (ft)	Mean Velocity (fps)	Depth (ft)	Mean Velocity (fps)	Depth (ft)	Mean Velocity (fps)	Depth (ft)	Mean Velocity (fps)	Depth (ft)	Mean Velocity (fps)	Depth (ft)	Mean Velocity (fps)
1	1.5	0.39	12.8	0.76	3.8	0.53	12.6	0.90	9.5	1.95	19.5	2.90
2	1.2	0.25	11.0	1.04	2.5	0.55	13.2	1.24	6.3	1.99	15.1	3.32
3	1.4	0.39	6.5	1.12	2.5	0.46	7.6	1.14	6.0	1.50	13.9	2.64
4	1.8	0.34	10.4	1.36	1.6	0.38	11.0	1.60	6.3	1.30	16.1	2.68
5	1.2	0.18	11.5	1.40	2.5	1.35	12.5	1.38	11.5	2.32	17.2	2.92

CONNECTICUT RIVER
HAVERHILL DEMONSTRATION SITE
VELOCITY MEASUREMENTS

Figure 41. Flow velocity readings (Source 39)

CHAPTER TEN

CONCLUSION

The various types of stream bank erosion and bank failure have been studied and well documented in both the laboratory and in the field. It has further been determined that soil erosion and bank failure is a function of a combination of many geotechnical and hydrological parameters, some of which have only recently surfaced in the last five to ten years. Due to the complex nature of these erosional processes and interaction of the variables and forces that cause stream bank erosion, the mechanics of erosional patterns on channels and stream banks are still not understood very well to date. It was for this reason that Congress enacted Public Law 93-251 which allowed the U.S. Army Corps of Engineers under the Section 32 Program to collect pertinent stream system data to study and evaluate new and existing stream bank protection methods. This program also put forth an effort to establish general design guidelines for future revetment projects. Therefore, all the concepts, principles and methodologies presented in this report are generalities and need to be tailored to specific erosion sites. This dilemma is further complicated by logistic and economic constraints, such as availability and cost of material, transportation, construction equipment and manpower.

CHAPTER ELEVEN

GLOSSARY

1. **Armor**: The man-made outer layer of revetment designed to take the full force of the wave action or the natural layer of erosion resistant material left after the finer materials have been eroded.

2. **Aggradation (Bed)**: The removal of stream bank material due to entrained sediment, ice, or debris coming in contact with the bank.

3. **Backwater Area**: The low-lying lands adjacent to a stream that may become flooded during periods of high water.

4. **Bank**: The side slopes of a channel between which the stream flow normally resides.

5. **Bed**: The bottom of stream channel.

6. **Bed Load**: The sediment that moves by saltation, rolling, or sliding in the bed layer of the stream.

7. **Bed Slope**: The inclination of the channel bottom.

8. **Blanket**: The material covering on all or part of a stream bank to prevent erosion.

9. **Braided Stream**: A relatively wide and shallow stream with multiple channels formed by islands and bars in the waterway.

10. **Buffer Zone**: An area of vegetation located between the top of a bank and adjacent pastures or cultivated land.

11. **Caving**: The collapse of a bank by undercutting due to erosion of the toe or an erodible soil layer above the toe.

12. **Channel**: A natural or man-made waterway that can pass flow.

13. **Confluence**: The junction point of two or more streams.

14. **Constriction (flow)**: A reduction in channel cross-section area that leads to greater stream velocities and/or greater water depths.

15. **Critical Shear Stress**: The minimum shear stress required by passing stream currents to initiate soil particle motion.

16. **Crossing (Crossover)**: The relatively short and shallow reach of a stream between bends.

17. **Cut Bank**: The concave wall of a meandering stream.

18. **Cutoff**: A newly formed short channel when a stream cuts or is realigned through the neck of an oxbow or horseshoe bend.

19. **Degradation (Bed)**: A progressive lowering of the channel bed due to scouring, which indicates a change in the stream systems discharge and sediment load characteristics is occurring

20. **Energy Grade Slope**: An inclined line representing the total energy of a stream system's flow from its highest to its lowest elevation. For the open-channel flow condition, the energy grade slope is located at a distance of $U^2/2g$ above the water surface, where U=velocity and g=acceleration due to gravity.

21. **Fetch**: The area in which waves are generated by wind having a rather constant direction and speed.

22. **Fetch Length**: The horizontal distance in the direction of the wind required to generate wind waves.

23. **Filter**: A layer of fabric, sand, gravel, graded rock, or combination of these materials placed or developed naturally to: prevent soil material from moving through the revetment by piping, extrusion, or erosion; prevent the revetment from sinking into the soil; and to permit natural seepage from the stream bank in order to prevent buildup of excessive hydrostatic pressure.

24. **Flood Frequency**: The relationship between flood magnitude and the time period expected before a given flood magnitude may occur again.

25. **Flow Regimes**: The state of flow and bed form at which a stream system is flowing (i.e. bed plane, dunes, standing waves, pools, etc.).

26. **Flow Slide**: Bank saturation to the point where the soil material acts like a liquid and causes stream bank failure in the form of a land slide.

27. **Geomorphology**: That branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and the buildup of erosional debris.

28. **Hard Point**: A process whereby "soft" erodible material is natural eroded or removed mechanically creating an area of nonerodible materials naturally or by placing hard material such as stone in its place.

29. **Head-cutting**: Channel bottom erosion moving upstream causing readjustment of the basin's slope and its stream discharge and sediment load.

30. **Hydraulic Radius**: The cross-sectional area of a stream divided by its wetted perimeter.

31. **Hydrograph**: A graph of the discharge or depth of water flowing by a particular point versus time.

32. **Lower Bank**: That portion of the stream bank having an elevation less than the mean water level of the stream.

33. **Mattress**: A material covering used to protect the stream bank against erosion.

34. **Meandering Stream**: A single channel waterway having a pattern of successive deviations in alignment and flow direction.

35. **Middle Bank**: That portion of the stream having an elevation approximately the same as the mean water level of the stream.

36. **Overbank Flow**: Water movement over the top of the stream bank due to a rising stream stage or inland surface runoff.

37. **Oxbow**: A horseshoe shaped reach of a former meander loop, that is left when the stream cuts a shorter channel across the narrow neck between two closely approaching bends.

38. **Piping**: The removal of noncohesive soil from the stream bank by seepage, or wave action.

39. **Point Bar**: The convex side of a stream bend that is built up due to sediment deposition.

40. **Rapid Drawdown**: The lowering of water against the stream bank more quickly than the stream bank can drain, possibly leaving it in a very unstable condition.

41. **Reach**: A portion of stream channel between any two points.

42. **Revetment**: A cover of erosion-resistant materials placed to protect a stream bank.

43. **Riparain**: Pertaining to anything connected with or adjacent to the stream banks.

44. **Rubble**: Rough, irregular fragments of concrete slab, masonry, or other suitable refuse of random size placed on a stream bank to retard erosion.

45. **Scour**: Localized erosion due to flowing water.

46. **Sediment Load**: The sediment carried through a channel by the stream flow.

47. **Stable Channel**: An equilibrium condition that has developed just the right slope and cross section for its channel to transport the water and sediment load delivered from upstream without any aggradation or degradation in the bed or bank.

48. **Stage**: Water-surface of a stream with respect to a reference elevation.

49. **Stream Bank Erosion**: The removal of soil particles or mass of particles from a stream bank surface primarily due to water action.

50. **Stream Bank Failure**: Collapse of a stream bank due to an unstable condition.

51. **Suspended-sediment Load**: That part of the sediment load that is transported within the fluid body (very little contact with bed).

52. **Thalweg**: The line extending down the channel that follows the lowest elevation of the streambed.

53. **Toe**: That point on a stream cross section where the lower bank terminates and the channel bottom or the opposite lower bank begins.

54. **Tractive Force**: The drag on a stream bank caused by passing water which tends to pull soil particles along with the stream flow.

55. **Upper Bank**: That portion of a stream bank having a greater elevation than the mean water level of the stream.

56. **Wave Attack**: The impact of waves on a stream bank.

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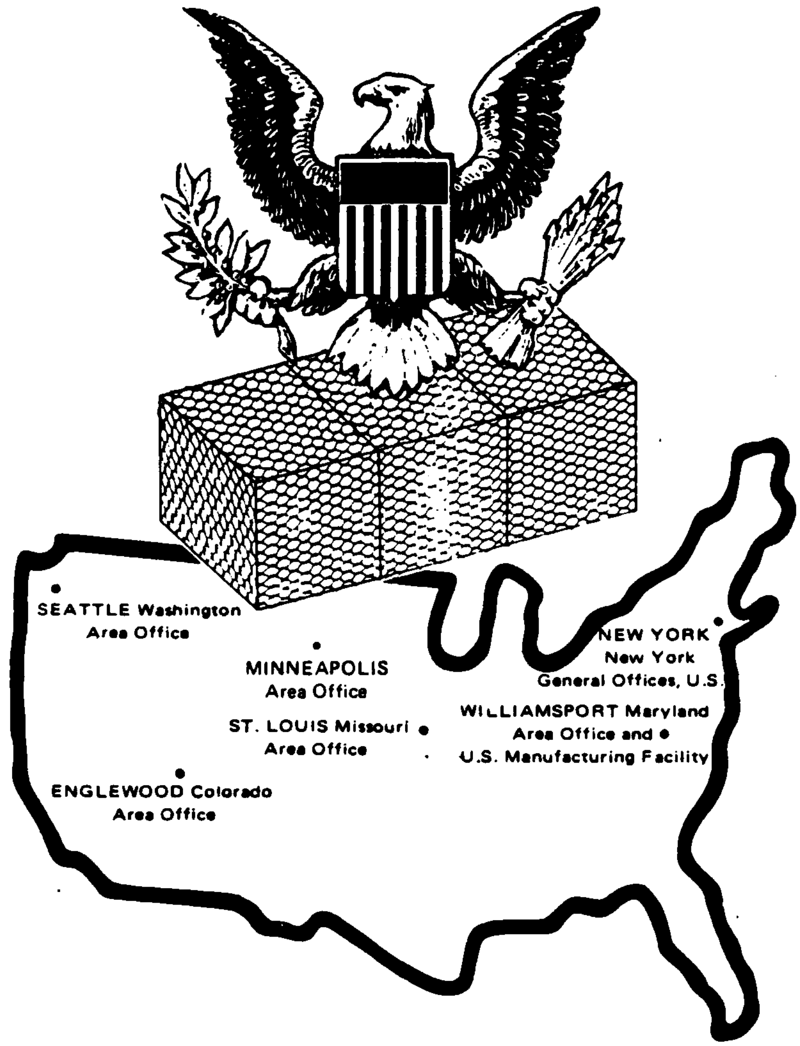
APPENDIX "A"
GABIONS



MACCAFERRI GABIONS, INC.

NEW YORK:	950 THIRD AVENUE, NEW YORK, N. Y. 10022	212-832-6780
ATLANTA:	3224 PEACHTREE RD. NE, ATLANTA, GEORGIA 30305	404-261-7178
SEATTLE:	P. O. BOX 3186 BELLEVUE, WASHINGTON 98009	206-455-4567
DENVER:	P. O. BOX 1356, ENGLEWOOD, COLORADO 80110	303-761-0819
MINNEAPOLIS:	SUITE 1421 RADISSON CENTER, 44 SO. 7TH STREET MINNEAPOLIS, MINN. 55402	612-341-3924
ST. LOUIS:	111 SOUTH BEMISTON AVE., ST. LOUIS, MISSOURI 63105	314-725-2477
WILLIAMSPORT	P. O. BOX 43A, WILLIAMSPORT, MARYLAND 21795	301-223-8700

PRINTED IN CANADA

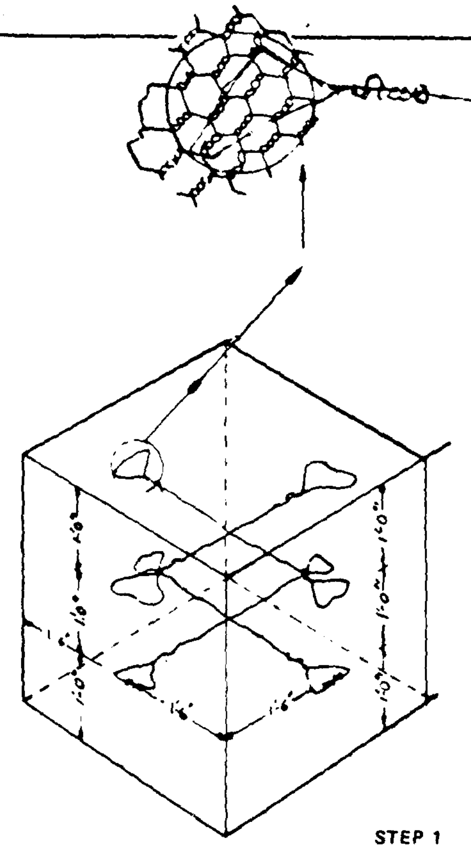
ASSEMBLING AND CONSTRUCTION

1. For easy handling and shipping, gabions are supplied folded into a flat position. They are readily assembled by unfolding and by simply wiring the edges together and the diaphragms to the sides.

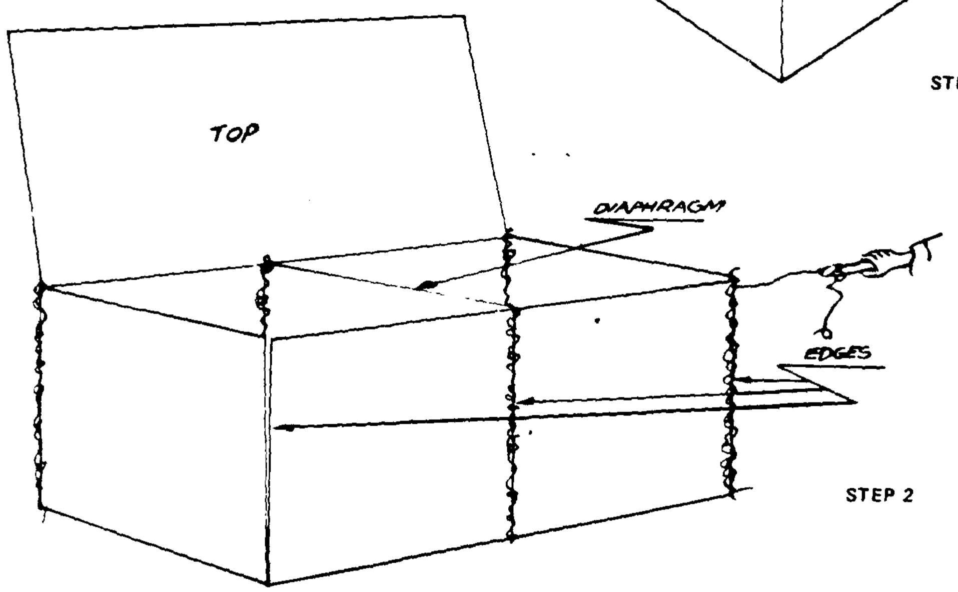
2. The gabions are filled to a depth of one foot, then one connecting wire is placed in each direction and looped around two meshes of the gabion wall. This operation is repeated until the gabion is filled.

3. Adjoining gabions are wired together by their vertical edges; empty gabions, stacked on filled gabions, are wired to the filled gabions at front and back.

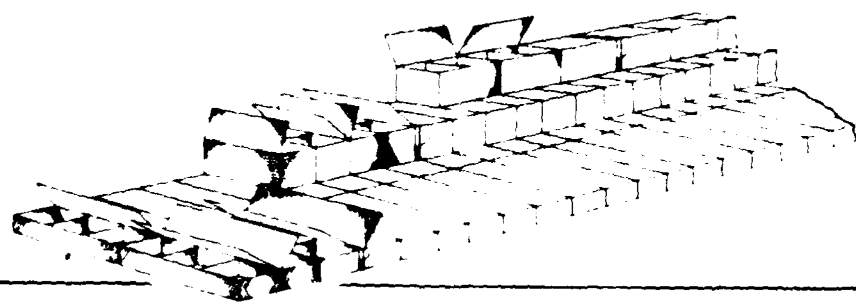
4. After the gabion is filled the top is folded shut and wired to the ends, sides and diaphragms.



STEP 1



STEP 2

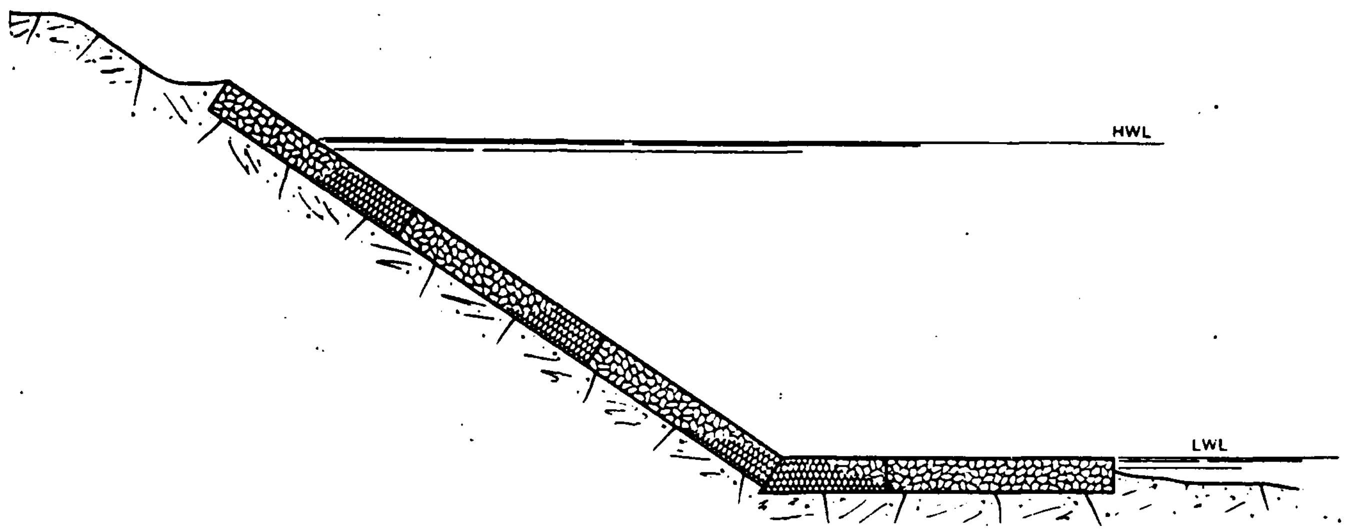


STEP 3

REVETMENTS

DESIGN DATA

The upper vertical limit of a revetment should extend above the expected high water line. The allowance for free board depends upon the velocity near the gabion revetment and at some locations upon the height of the waves that might be generated on the water surface. Where the stream channel is composed of sand or silt, revetments should be protected by an apron, fig. 22 or by a toe wall, fig. 21.



Fig

Fig. 23 18" gabion revetment provides an effective and economical protection for the bridge

On the outside of curves or sharp bends, scour is particularly severe and the toe of the revetment should be protected by a wider apron. The purpose of the toe protection is to prevent undermining, not to support the revetment. The revetment should extend both upstream and downstream from the points of reverse curvature on the outside of a curved channel. Bank protection is usually not required on the inside of the curve unless return of over bank flow creates a scour problem. On a straight channel the beginning and end of a gabion revetment should be protected by cut-offs.

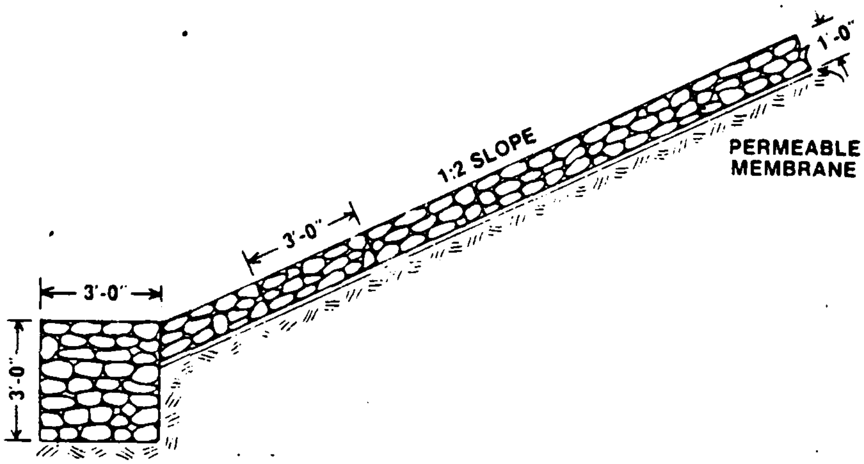


Fig. 24

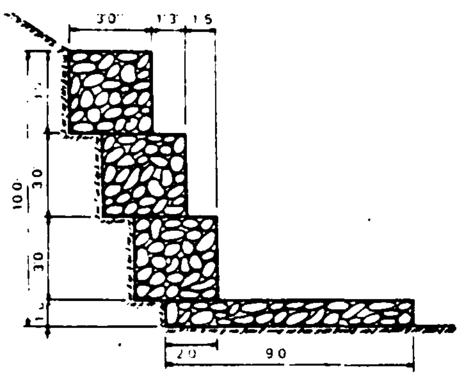


Fig. 25

CHANNEL LINING

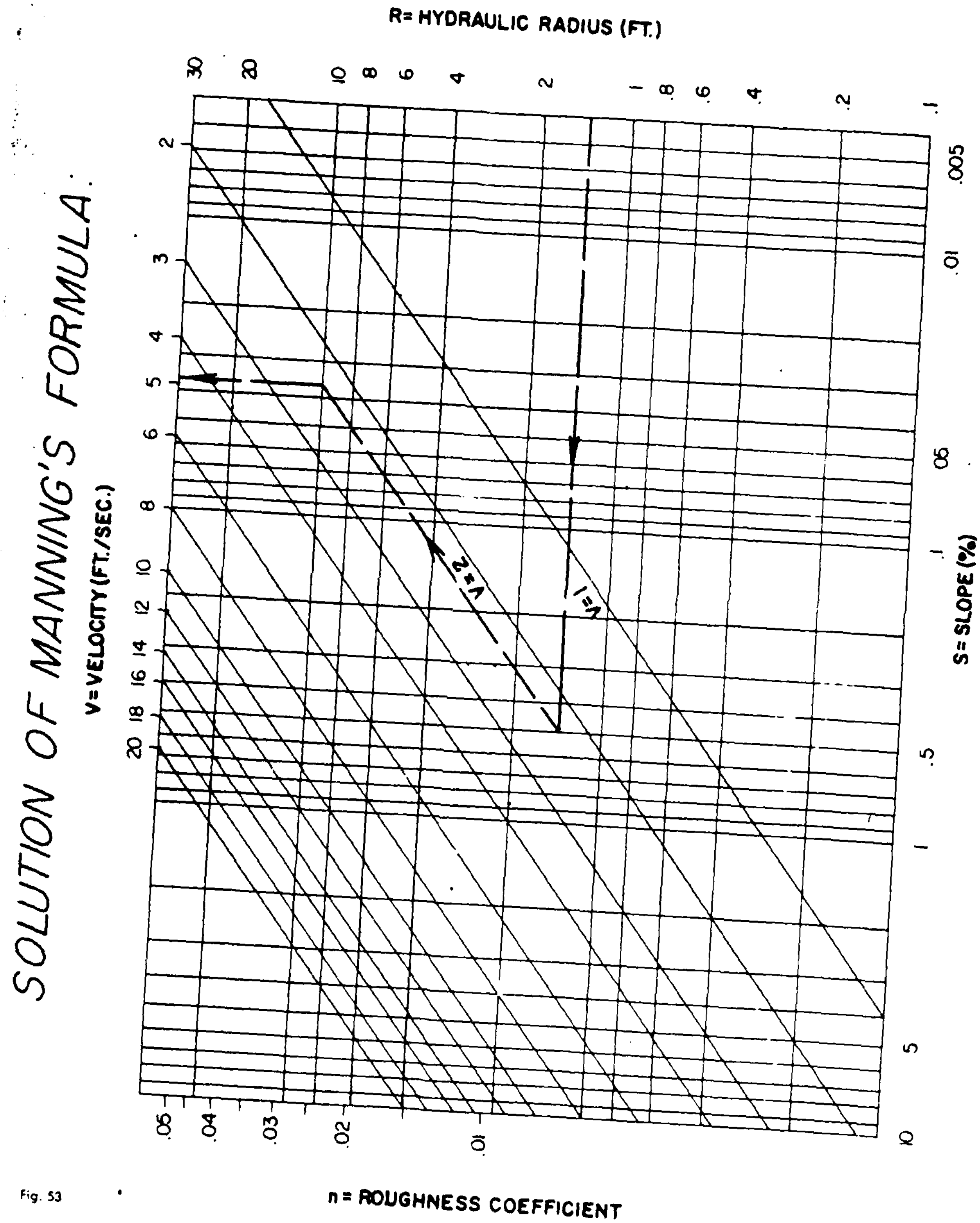
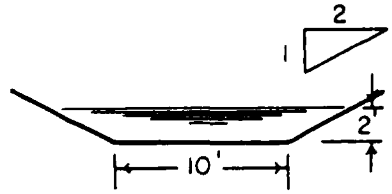


Fig. 53

EXAMPLE OF SOLUTION OF MANNING'S FORMULA:

GIVEN:
Trapezoidal channel having bottom width = 10 feet, side slopes 1 on 2, depth of flow = 2 feet, slope = 0.5%
The channel is lined with gabions filled with stone having a mean size of 4".
Find the velocity and discharge in the channel.



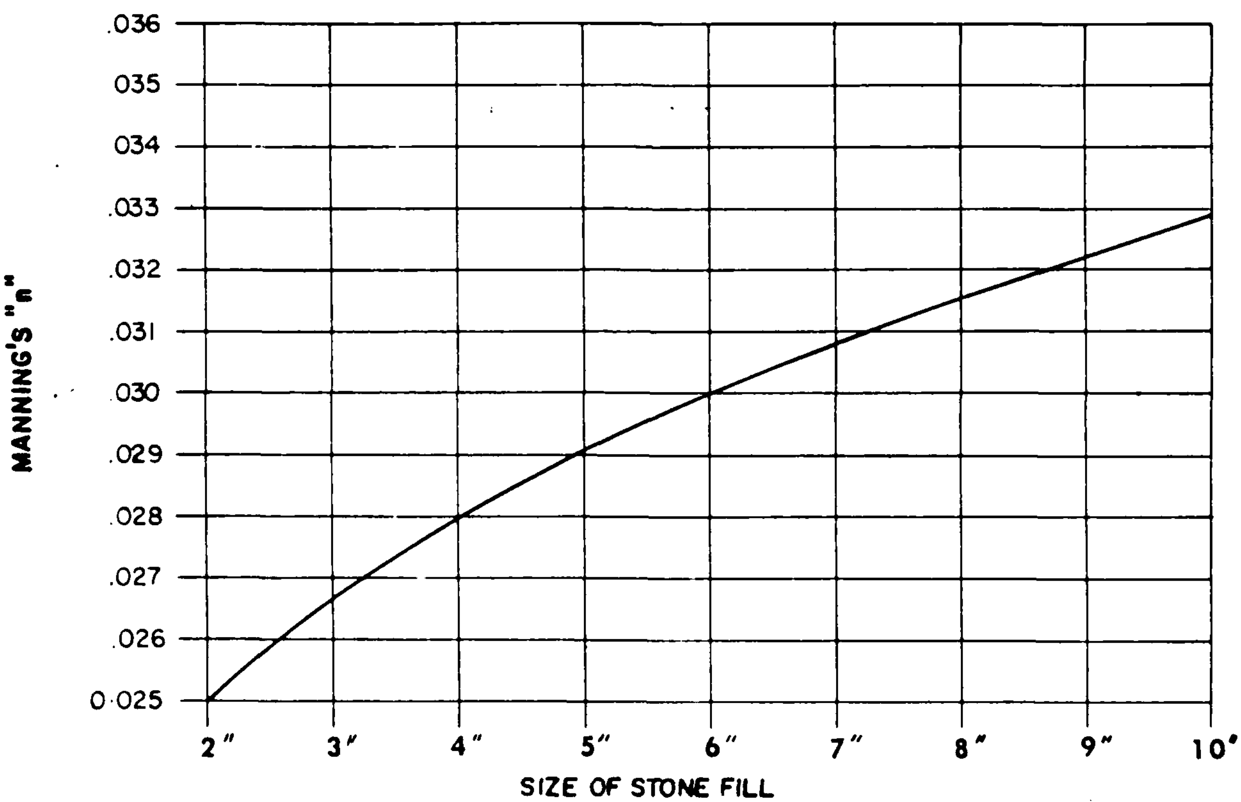
SOLUTION

Flow area = $\frac{(10 + 18)}{2} \times 2 = 28$ square feet

Wetted Perimeter = $10 + 2\left(\sqrt{2^2 + 4^2}\right) = 19$ feet.
Hydraulic Radius = A/WP = 28/19 = 1.5 feet.
Since hydraulic radius is less than 5 feet, the roughness factor of the gabions is obtained from the graph as 0.028

FROM THE CHART
1) Locate the intersection of R = 1.5 and S = 0.5%
2) Follow the diagonal line to the intersection of n = .028
3) Proceed vertically to top of chart to find V = 4.9 fps
Discharge, Q = AV = 28 X (4.9) = 137 cfs

VARIATION OF MANNING'S "n" WITH SIZE OF STONE FILL



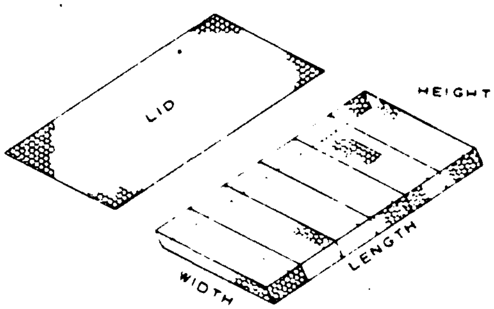
NOTE:
When hydraulic radius is greater than about 5 feet, a constant value of 0.025 for "n" may be used if the stone fill is between 2" and 10" in size.

WIRE SPECIFICATIONS

All steel wire used in the Revet Mattress is heavily galvanized with zinc coating exceeding Federal Specificati- requirements (QQ W 461g, Class 3).

GALVANIZED REVET MATTRESS

MESH-OPENING	WIRE FOR NETTING	WIRE FOR SELVAGES & CORNERS	WIRE FOR BINDING	ZINC-COATING
Type 6 x 8 (2½" x 3¼")	2.2 mm (.0866") ± 2½% approximately U.S. Gauge 13½	2.70 mm (.1063") ± 2½% approximately U.S. Gauge 12	2.20 mm (.0866") ± 2½% approximately U.S. Gauge 13½	Oz. 80-Sq. Ft Oz. 80-Sq. Ft



P.V.C. REVET MATTRESS

MESH-OPENING	WIRE FOR NETTING	WIRE FOR SELVAGES & CORNERS	WIRE FOR BINDING	ZINC-COATING
Type 6 x 8 (2½" x 3¼")	2.2 mm (.0866") ± 2½% approximately U.S. Gauge 13½	2.70 mm. (.1063") ± ½% approximately U.S. Gauge 12	2.20 mm (.0836") ± 2½% approximately U.S. Gauge 13½	PVC Coating 0.[illegible] mm. (0.[illegible]15")

DESCRIPTION

Maccaferri Heavy Duty Revet Mattress (Reno Mattress) is a wide flat rectangular basket manufactured from heavily galvanized steel wire mesh of triple twist hexagonal weave. Each Revet Mattress unit is subdivided lengthwise into compartments by diaphragms.

At the job site the Revet Mattress is unfolded and assembled by simply lacing both ends and diaphragms to the unit sides. The assembled mattresses are securely laced to each other and subsequently filled with 3"-4" stone. The lids are then laced to each unit forming the finisned structure.

SUPPLY AND DELIVERY

Revet Mattresses and lids are supplied folded [illegible] and stacked together in bundles for convenient shipping [illegible] handling. Sufficient lacing wire is supplied with the mattresses in coils. All sizes listed below are available in quantity from warehouses located across the country. Please contact your nearest Maccaferri office for details.

HEAVY DUTY GALVANIZED REVET MATTRESS

9" THICK

LETTER CODE	MESH OPENING	LENGTH	WIDTH	NO. OF COMP'TS.	AREA COVERED	CAPACITY CU. YD.
S	2½" x 3¼"	8'	6'6"	4	52 sq. ft.	1.44
T	2½" x 3¼"	10'	6'6"	5	65 sq. ft.	1.80
U	2½" x 3¼"	12'	6'6"	6	78 sq. ft.	2.16

P.V.C. COATED REVET MATTRESS

9" THICK

LETTER CODE	MESH OPENING	LENGTH	WIDTH	NO. OF COMP'TS.	AREA COVERED	CAPACITY CU. YD.
S	2½" x 3¼"	8'	6'6	4	52 sq. ft.	1.44
T	2½" x 3¼	10	6'6	5	65 sq. ft.	1.80
U	2½" x 3¼	12	6'6	6	78 sq. ft.	2.16

SPECIFICATION 803-GABIONS

803.1 GABION DESCRIPTION AND USE

Gabions are hexagonal mesh wire baskets. The mesh is produced by a triple twist. These gabions are hexahedral in shape, and when laced together and filled with rocks, are utilized in or adjacent to waterways as bank revetment, sills, retaining walls, and other soil stabilization structures.

Sea type gabions differ from standard galvanized gabions in that one gauge lighter wire is utilized in field mesh, selvage and edge wires as compared to that utilized in standard galvanized gabions; in addition, PVC coating is given to all wires in sea type gabions. All wires are subject to a tolerance limit of ± 3%.

803.2 WORK

This work shall consist of furnishing, assembling, tieing, installing, filling with approved stones, and final closing of gabions in accordance with these specifications and within reasonably close conformity to the lines, grades, widths and depths shown on the drawings or as directed by the Engineer.

803.3 MATERIALS

a) Galvanized Gabions

The wire used in the body of the mesh shall be made of galvanized steel wire having a minimum diameter of 3.00 mm. (0.118"). The tensile strength of the wire shall be in the range of 60,000 to 75,000 psi, determined in accordance with latest revision of ASTM Designation A 392. The minimum zinc coating of all wires shall be 0.80 oz. per square foot of uncoated wire surface as determined by tests conducted in accordance with latest revision of ASTM Designation A-90.

The selvedge and edge wires on each sheet of mesh shall be galvanized steel wire having a diameter of 3.90 mm. (0.153").

The connecting or tie wires are to meet the same specification as the wire used in the body of the mesh except that tie or connecting wires for gabion cages shall have a diameter of 2.20 mm. (0.086").

All wire used in the manufacture and assembly of the mesh shall equal or exceed Federal Specification QQ-W-461G, wire, steel, carbon (Round, Bare and Coated) including the following specific requirements: finish 5, Class 3, weight of zinc coating 0.80 oz. per square foot of mesh. In addition, the wire used, including tie or connecting wire shall be certified by mill test report(s) showing compliance with specification requirements.

b) Sea type Gabions

When called for in the plans or in any other specification, Sea type Gabions shall be made of heavily galvanized steel wire (complying with Federal Standard QQ-W-461-G Class III), then coated with PVC plastic.

The heavily galvanized core wire used for the body of the mesh shall be 2.70 mm. (0.106") in diameter. The overall diameter (core wire plus plastic coating) shall be 0.149 inches in diameter.

The wire used for the selvedge and the edge shall be heavily galvanized core wire of 3.40 mm. (0.133") in diameter, coated with plastic and having an overall diameter (core wire + plastic coating) of 0.181 inches.

The minimum zinc coating of all wires shall be 0.80 oz. per square foot of uncoated wire surface as determined by tests conducted in accordance with latest revision of ASTM designation A-90.

The connecting wire supplied with all Sea type gabions and necessary for all wiring operations shall be heavily galvanized core wire, 2.20 mm. (0.086") in diameter, coated with plastic and having an overall diameter (core wire + plastic coating) of 0.126 inches.

c) Filling Material

Rock used in the gabions (see type and galvanized) shall be sound and durable, from any source approved by the Engineer. Rock shall have a specific gravity of at least 2.25 and shall be resistant to the action of air and water. Flacking or fragmental rock will not be permitted.

All rocks shall be hard, free from laminations, weak cleavages and undesirable weathering, and of such character that it will not disintegrate by the conditions to be met in handling and placing.

Suitable samples of the rock which the Contractor proposes to use in the work shall be furnished by the Contractor and delivered at his expense to the Engineer for approval prior to delivery of any such material to the site of the work, accompanied by certified test results by an approved laboratory, showing that the rocks meet the specified requirements. The Contractor shall not deliver any of the proposed rocks to the site of work until approval of the test samples by the Engineer has been received.

d) Filter Material (when required)

A WOVEN filter cloth shall be firmly secured underneath all revet gabions placed on side slopes and underneath all gabions used to transition side slopes. Filter cloth shall be woven in minimum width of 12 feet and shall be equal to NICOLON FILTER CLOTH as supplied by: Unites States Textures Sales Corporation, 4229 Jeffrey Drive, Baton Rouge, Louisiana, 70816, telephone (504) 292-3010; Bradley Materials Co., Inc., P. O. Box 254, Valparaiso, Florida, 32580, telephone (904) 678-1789.

NICOLON FILTER CLOTH shall comply with the following requirements:

Composition:	Warp - Polyethylene monofilament Fill - Polypropylene multifilament
Tensile Strength:	200# in both directions
Equivalent Opening Size:	(U. S. standard sieve) 70 to 80
Water Permeability:	Energy drop 0.64 (10^{-2}M) Hydraulic gradient 1.05
Open Area:	20% to 25%
Weight:	7 ounces/sq. yd.
Width:	12 feet minimum

The necessary precautions and Manufacturer's recommendations shall be followed to assure proper installation of the filter material.

803.4 DIMENSIONS

a) Sea Type and Galvanized Gabions

Gabion dimensions shall be supplied, as specified in the plans, in various lengths and heights, subject to tolerance limit of ± 5%.

The wire mesh should form hexagonal openings about 3 by 4 inches of uniform size. The opening shall not exceed 4 1/2 inches in the largest dimension and 3 1/4 inches in the shortest dimension.

No rock shall be less than 4 inches (minimum dimensions) nor greater than 8 inches (maximum dimensions). The rock shall be well graded between limiting sizes.

803.5 TOLERANCES

Dimensions for heights, lengths and widths are subject to a tolerance limit of ± 5%. Wires used for a selvedge, for the body of the mesh and for connecting are subject to a tolerance of ± 3%. The mesh opening is subject to a tolerance of ± 5%. PVC coating for Sea type gabions is subject to a tolerance of ± 5%.

803.6 FABRICATION DETAILS

Gabion basket shall be fabricated in such a manner that the sides, ends, lid and diaphragms can be assembled at the construction site into a hexhedral basket of the specified sizes. Gabion baskets shall be of single unit construction. The base, lid, ends and sides shall be woven, either into a single unit or one edge of those members connected to the base section of the gabion basket, in such a manner that the strength and flexibility at the point of connection is at least equal to that of the mesh or as shown on the table for minimum strength below.

Where the length of the gabion basket exceeds its horizontal width, the basket shall be equally divided into cells by diaphragms of the same mesh and gage as the body of the basket. The gabion basket shall be furnished with the necessary diaphragms secured in proper position, woven to the base.

All perimeter edges of the mesh forming the gabion basket shall be securely selvedged so that the joints formed by tying the selvedge have at least the same strength as the body of the mesh, (see table below).

Connecting wire shall be supplied in sufficient quantity for securely fastening all edges of the gation and diaphragms, and to provide for eight (8) internal connecting wires in each cell.

The wire mesh shall be fabricated in such a manner as to be non-reveling. This is defined as the ability to resist pulling apart at any of the twists or connections forming the mesh when a single wire in a section of mesh is cut and the section of mesh then subjected to the load test described in these specifications.

The structural tests shall be conducted in accordance with the State of Colorado Department of Highways, Colorado Procedure CPI-6130 "Method of Conducting Strength Tests of Gabions." The table below shows the minimum strengths required:

TABLE FOR MINIMUM STRENGTH

	Required Minimum Strength in lbs. per linear foot — GABIONS Galvanized	P.V.C. Coated
1-Wire Mesh		
a)-pulled parallel to wire twist	3,400	3,000
b)-pulled perpendicular to wire twist	1,000	1,000
2-Connection of selvedge wire to mesh	2,200	2,000
3-Conn. of end diaphragm to selvedge wire	1,500	1,500
4-Conn. of center diaphragm to gabion base	1,000	1,000

803.7 ASSEMBLY

The gabions shall be shipped and supplied folded flat. The unfolding, assembly, filling and installation is carried out at the construction site.

Gabions are packed in bundles. The bundles should be stored or brought to assembly area so bundles can be unpacked with a minimum of travel by workmen to and from bundle storage area. Each gabion, when removed from the bundle, shall be placed on a hard flat surface. Each gabion is then unfolded; generally, it is unfolded lengthwise first. The gabion is next opened to the full flat position.

The gabion ends and diaphragms are folded up to the vertical position. The base of the end and/or diaphragms are firmly attached to the body of the gabion, therefore, no additional tying is required at this location.

The top selvedged edge extension of the ends and diaphragms panels are folded out to extend fully in the horizontal position.

The front panel, which is the large side panel without the lid, is folded up to the vertical from horizontal position. The selvedge or perimeter wire of the ends and diaphragms is extended under the selvedge or perimeter of the front panel.

The selvedge extension is then folded up and over the top of the front panel selvedge to secure the diaphragms into vertical position. The selvedge wire is looped and the end is extended downward on the inside of the gabion. Care must be taken to maintain alignment of ends or diaphragms in the vertical position. This is attained by visual inspection of the looping of the diaphragm selvedge over the side panel selvedge at a point directly above the base attachment point of the diaphragms.

The rear side panel and lid are next folded up using the selvedge weave wire as a guide. The selvedge weave wire is recognizable since it is 2 gauges heavier than the netting of mesh wire of the body of the gabion.

The selvedge wire at the top of the diaphragm or ends is extended below the weave selvedge and folded up and through the mesh opening directly above and adjacent to the selvedge weave wire. The wire is looped and extended vertically downward on the inside of the gabion unit.

The gabion is now ready for final assembly lacing. The wires or connecting wire shall be used to join the flaps or panels together.

803.8 <u>INSTALLATION</u>

Gabions shall be installed according to the manufacturer's recommendations. The gabions shall be placed on a smooth foundation. Final line and grade shall be approved by the Engineer.

Each basket shall be erected in accordance with assembly diagrams furnished by the Contractor and approved by the Engineer. These gabion baskets shall be securely fastened to all adjacent gabion baskets, and the amount of wire used shall be sufficient to provide the same strength as the body of the mesh.

All selvedges that are in contact between units are laced excluding the bottom selvedges in contact with soil material.

Horizontal connecting wire shall be inserted as the rockfilling proceeds. The area behind and around the filled baskets shall be backfilled to the finished lines of the channel, using approved material.

A standard fence stretcher, chain fall, or iron rod may be used to stretch the wire baskets and hold alignment.

The gabions shall be filled with stone carefully placed by hand and/or machine to assure alignment and avoid bulges. A minimum of voids shall be attained. In this case void is any hollow in which a rock of the specified sizes fit. Wherever connection wires are required alternate placing of rock and connection wires shall be performed until the gabion is filled. The last layer in each gabion basket shall completely fill the gabion basket, so the lid when secured will bear on the gabion filler. After a gabion has been filled, the lid shall then be secured to the sides, ends and diaphragms with the tie wires or connecting wires to increase the strength of the basket.

All recommended field connections shall develop connections strong enough so that the failure occurs in the mesh rather than in the lacings.

Care shall be taken when placing aggregates to assure that the sheathing on PVC and galvanized coated gabions will not be broken or damaged.

803.9 TESTS

a) Zinc Coating

The test shall be conducted in accordance with details described in ASTM designation A-90.

b) Tensile Strength

The test shall be conducted in accordance with details described in ASTM A-392, except that strength shall be as listed above.

c) Resistance of the PVC Coating of Sea Type Gabions

The PVC color is black which gives the best results under all conditions of exposure. The protective coating must be resistant to the air and sea water and must meet the following tests:

1) Immersion of the wire for 20 hours in Hydrochloric acid (solution composed of 50% H_2O and 50% HCL concentration 21 Baume-Test Temperature 15^o C) or immersion for 60 hours in a saturated solution of salt water at 15^o C without noticeable loss of weight due to corrosion of the coating material and without any reduction of the wire's diameter.
2) After immersion of a length of the coated wire in a 3.5% solution of Potassium Permanganate ($KMnO_4$) for a continuous period of fifty hours at an ambient temperature, the maximum penetration between the coating and the core wire from a square cut end shall be 12 millimeters (0.472 inches).
3) The protective coating will not be altered or deformed by temperature ranging between + 158^oF and - 40^oF.

803.10 CERTIFICATION

Each shipment of Gabions to a job site shall be accompanied by a certification which states that the materials conform to the requirements of this specification. A shipment shall consist of all material arriving at the job site at substantially the same time. The certification shall be on company letterhead and shall be signed by an officer of the company having legal authority to bind the company.

803.11 METHOD OF MEASUREMENT

The quantity to be paid for under this item shall be the number of cubic meters of gabions measured in their final position as specified on the drawings or ordered by the Engineer.

803.12 BASIS OF PAYMENT

The quantities determined as provided above, will be paid for at the contract price per unit of measurement for the pay item listed below, which price and payment shall constitute full compensation for furnishing and placing filter cloth, wire baskets and rock, and for all labor, materials, equipment, accesories, and tools necessary to complete the work described in this section.

Payment will be made under

Pay Item	Pay Unit
Gabions	Cubic meter

COLORADO PROCEDURE CP I 6130

METHODS OF CONDUCTING STRENGTH TESTS OF GABIONS

SCOPE

1.1 To provide a systematic basis for obtaining engineering data on Gabion wire mesh and wire mesh cage.

NOTE - Wires are to be tested in accordance with Federal Specification QQ-W-461 G. See specifications for gage finish and spelter class. Wire taken from wire mesh shall not be tested as an individual wire.

NOMENCLATURE

2.1 Names of the elements of a typical gabion structure as considered in this test procedure are shown in Figure 1 and listed below.

2.1.1 Gabion - Prefabricated wire mesh cage.

2.1.2 Twist - An interweaving together of wires to transmit load and prevent ravelling.

2.1.3 Wire - The wire in the body of the mesh used to fabricate the main body of the gabion.

2.1.4 Wire Mesh - The mesh used in the main body and components of the gabion.

2.1.5 Edge Wire - The wire used to form the edge of the mesh, being interwoven with the peripheral, continuous field wire.

NOTE - The edge wire runs parallel to the axis of twist of the wire mesh.

2.1.6 Selvage Wire - The wire used to close off the mesh where the wires are terminated, except on diaphragms and ends, where they are connected to the main body of the gabion.

NOTE - The wires are wound around the selvage wire to form the terminal connection, hence the selvage wire runs perpendicular to the axis of wire twist.

2.1.7 Field Connection - The wire or ring connection recommended by the supplier and made by the erector to tie adjacent wire mesh gabions together by lacing or tying through the edge and selvage wires.

NOTE - This wire type is not shown in Figure 1.

2.1.8 Spreader Bar - A compression strut positioned horizontally across a test specimen, dimensioned to prevent the specimen from contracting laterally during a longitudinal mesh tension test and to provide a 1/4-inch clearance between the mesh and the bar face. It shall be long enough to include 7 repetitions of the mesh pattern between grips.

NOTE - This bar, used at repetitions of the mesh pattern, should consist of a light weight 2 x 4 timber strut or 7/8" diam. steel bar with a bolt and washers at each end. The combined weight of spreader bars used in a test shall not exceed 0.5 percent of the ultimate strength of the specimen being tested.

2.1.9 Carabiner - A nominally 1/2-inch diameter steel spring clevis used to transfer load from the edge or selvage wires to the opposite side of the test specimen in Edge Wire or Selvage Wire Tests, (See Figure 2).

2.1.10 Block - A shaped washer used as a spacer between the gabion wires and the testing machine head bolts or spreader bar bolts to transfer the bolt load to the mesh without allowing the wires to deform significantly from their field - use configuration.

2.1.11 Non-raveling - The term used to describe the action of a wire twist which binds up after an initial wire fracture, causing additional adjacent wires to fracture before separation of the twist by unraveling. Also referred to as self-locking construction.

TEST OF WIRE MESH FOR NON-RAVELING CONSTRUCTION, MESH ELASTICITY, AND TENSILE STRENGTH

3.1 Purpose - To determine the percentage of elongation of the wire mesh under loading; demonstrate its self-locking construction; determine the tensile strength of the mesh.

3.2 Test Specimens - The wire mesh specimens shall be representative of proper field construction as to materials, mesh geometry, and workmanship, and shall be as large as practical to minimize the effect of variations. The width of a specimen shall not be less than seven repetitions of a mesh pattern, nor shall the length be less than fourteen. The test shall be run with the load applied parallel to the axis of twist and repeated on a separate test specimen with the load applied perpendicular to the axis of twist.

3.3 Apparatus:

3.3.1 The testing machine or load measuring apparatus shall comply with the requirements of ASTM Methods E4, Verification of Testing Machines. The machine shall measure total pounds pull with an accuracy and readability of at least 3.0 percent (See Figure 3) and be capable of pulling a uniform load across the width of the specimen.

3.3.2 The apparatus shall grip the wire in such a manner as to allow the wire failures to occur at least one mesh pattern away from the gripping points. If a failure occurs in a wire leading directly to a gripping point, that specimen shall be rejected, and not included among the tests reported.

3.4 Procedure:

3.4.1 Insert the wire into the machine grips and spreader bar attachment points such that the gripped wires will be maintained in the mesh geometry characteristic of field use and attached in such a manner as to eliminate failure at the grips.

NOTE - The grips may be left loose until the preload is applied to allow the wires to seat.

3.4.2 Apply the load at a uniform rate not to exceed 50 pounds per second nor 3 percent of the mesh ultimate strength per second. The load shall initially be taken to a preload of 20 percent of the specified minimum strength and the machine head travel stopped. The mesh gage dimensions shall be recorded at this time and taken as the initial dimensions of the specimen where such dimensions are required. Loading shall then continue uniformly in increments of 10 percent of the specified minimum strength until first fracture or unwrapping of an individual wire in the system occurs.

NOTE - Machine head travel at each load increment or sequential incident of wire failure may be stopped for recording pertinent information such as load, fracture type, resulting mesh geometry and elongation and resulting reduction in wire gage.

Deformation Measurement - The distortion of the mesh or changes in gage length shall be measured to an accuracy consistent with reporting the percent elongation to the nearest 0.5 percent.

3.4.3 Continue the loading well beyond the point of first failure to evaluate the mode of progressive destruction and to observe twist self-locking performance.

3.5 Calculations:

3.5.1 The deformation of the specimen, up to first failure shall be measured with sufficient accuracy to evaluate the elongation of the mesh to the nearest 0.5 percent.

3.5.2 In the calculation of percent elongation of the specimen, the gage dimensions taken on the specimen shall be in excess of 90 percent of the overall length of the specimen, but shall not include the regions immediately adjacent to the testing machine grips, unless it is proven that such regions do not exhibit deformations significantly different from the deformation of typical interior mesh patterns.

3.5.3 The percent elongation shall be obtained by plotting the curve of load versus displacement, translating the resulting curve so that the curve passes through zero, then calculating the percent using the corrected displacement values.

Thus:

$$\text{Percent Elongation} = 100\ (d_i + d_o)\ /\ Lg$$

Where:

d_i = original elongation of mesh gage length,

d_o = the change in elongation necessary to pass the curve through zero, and

Lg = the gage length of the mesh.

3.6 Report:

3.6.1 Elongation - Report the original gage dimension at the 20% preload, and at each of the 10% increments, labeling the load that produced the first wire failure and the name of the wire that failed. Draw a smooth curve from this data with the curve translated through zero using the formula in 3.5.

3.6.2 Non-raveling - State whether or not unraveling occurred for both tests. Describe any unraveling that did occur.

3.6.3 Tensile Strength - Report the actual load and the pounds per lineal foot reached to produce the first break.

3.7 Results:

3.7.1 Elongation - The percent elongation reached before the first wire break must exceed the specified percentage.

3.7.2 Non-raveling - No more than one twisted wire in the wire mesh, either broken or unbroken, shall completely untwist during the test.

3.7.3 Tensile Strength - The first break in the wire of the mesh shall not occur until the specified pounds of pull per lineal foot of width has been reached. Width to be measured between left and right end connecting grips, center to center.

TEST OF EDGE WIRE CONNECTION TO WIRE MESH IN CAGE

4.1 Purpose - To determine the force necessary to pull the edge wire away from the wire mesh. Failure of the wire in the mesh prior to failure of the edge wire itself is not a mistest.

4.2 Test Specimen - The specimen shall consist of two identical sections of wire mesh, joined together at each mesh repetition by carabiners or equivalent connecting devices at the two adjacent edge wires. Figure 3 shows a similar configuration as done for selvage wire test. Each section of wire mesh shall be at least 7 repetitions by 7 repetitions of the mesh pattern in size.

NOTE - The specimen shall not include selvage, lacing, or other forms of wire connectors, other than edge wires to be tested.

4.3 Apparatus - See 3.3.

4.4 Procedure:

4.4.1 Installation - The two part specimen shall be positioned vertically in the testing machine so as to apply a uniformly distributed vertical load parallel to the length of the specimen.

NOTE - Thus the edge wires will run horizontally at mid-height of the specimen, and shall be connected by carabiners at each repetition of the mesh pattern. The carabiners shall be placed at the midpoint of the mesh opening between points of contact of edge wire and the body of the mesh. The specimen field shall be restrained against lateral contraction by horizontal spreader bars positioned at each repetition of the mesh pattern, and attached to the extreme outside wires only. The free ends of the edge wires shall be attached to additional spreader bars to prevent lateral contraction. The connection of the edgewire to the spreader bar posts shall be tight prior to loading. The grips of the testing machine and the wire spreader bars shall be tightened after the preload has been applied.

4.4.2 Loadings - Uniaxial stretch shall be applied in accordance with Paragraph 3.3

4.5 Report - The report shall include the following items: Detailed description of the test setup showing specimen configuration and mesh pattern, dimensions and load transfer details; the strength at first wire failure and at the maximum load reached, in pounds and pounds per linear foot, or their metric equivalents. The sequence and modes of failure shall be discussed.

4.6 Results:

4.6.1 The edge wire shall not break before a wire of the mesh breaks.

TEST OF SELVAGE WIRE CONNECTION TO WIRE MESH OF FABRICATED GABION

5.1 Purpose - the purpose of this test is to determine the force necessary to pull the selvage wire away from the wire mesh.

NOTE - Failure of the wire in the mesh or unwrapping of the wire from the selvage wire prior to failure of the selvage wire itself is not a mistest.

5.2 Specimen - The specimen, as shown in Figure 2, shall consist of two identical sections of wire mesh joined together at the center of each repetition of the mesh pattern by carabiners or equivalent connecting devices at the two adjacent selvage wires. Each section of wire mesh shall be at least 7 repetitions by 7 repetitions of the mesh pattern in size. The test should be repeated 3 times with samples taken from different edges of the same or different gabions.

NOTE - The specimen shall not include edge, lacing or other forms of wire connectors, other than the selvage wires to be tested.

5.3 Apparatus - See 3.3

5.4 Procedure:

5.4.1 Installation - The two part specimen shall be positioned vertically in the testing machine so as to apply a uniformly distributed vertical load parallel to the length of the specimen.

NOTE - The specimen field shall be restrained against lateral contraction by horizontal spreader bars positioned at alternate repetitions of the mesh pattern, and attached to the extreme outside wires only. The free ends of the edge wires shall be attached to additional spreader bars to prevent lateral contraction. The connection of the wires to the spreader bar posts shall be tight prior to loading. The grips of the testing machine and the wire spreader bars shall be tightened after the preload has been applied.

5.4.2 Loading - Uniaxial stretch shall be applied in accordance with Paragraph 3.3.

5.5 Report - The report shall include the following items: Detailed description of the test setup showing specimen configuration and mesh pattern dimensions and load transfer details; the strengths at first wire failure and at the maximum load reached, in pounds and pounds per linear foot or their metric equivalents. The average strengths at first failure and at maximum strength reached shall be given. The sequence and modes of failure shall be discussed.

5.6 Results:

5.6.1 First wire break shall not occur until specified load has been applied. The selvage wire shall not pull away from the field wire mesh until the specified minimum load for "connection of selvage wire to mesh" has been reached.

TEST OF SPECIFIED LACING BETWEEN FIELD WIRE MESH PARTS OF ASSEMBLED GABION

6.1 Purpose - The purpose of this test is to evaluate the adequacy of lacing wire pattern in transferring load between mesh fields.

NOTE - Failures of the mesh, edge, or selvage wires prior to failure of the lacing wire itself are not a mistest.

6.2 Specimen - The specimen shall consist of two identical sections of field wire, identically oriented with respect to the axis of twist, and joined together by lacing wire or rings in the pattern or sequence of lacing specified by the manufacturer. Each section of wire mesh shall be at least 7 repetitions by 7 repetitions of the mesh pattern in size and include an edge or selvage wire along the appropriate side. The edge or selvage wire connections used for this test must be identical to connections that were tested and shown to meet the specified minimum strength.

6.3 Apparatus - See 3.3.

6.4 Procedure:

6.4.1 Installation - The two part specimen shall be positioned vertically in the testing machine so as to apply a uniformly distributed vertical load, parallel to the length of the specimen.

NOTE - The specimen shall be restrained against lateral contraction by horizontal spreader bars positioned at each repetition of the mesh pattern.

6.4.2 Loading - Apply uniaxial stretch in accordance with Para. 4.2.

6.5 Report - The report shall include the following items: Detailed description of the test setup showing specimen configurations and mesh pattern, dimensions and load-transfer details, and the strengths at first wire failure and at the maximum loads reached, in pounds and pounds per linear foot or their metric equivalents. The average strengths at first failure and at maximum load shall be given. The sequence and modes of failure shall be discussed.

6.6 Results:

6.6.1 The wire of the mesh shall break, or unwrapping of the mesh from the selvage wire shall occur, before the lacing breaks.

MESH NOMENCLATURE

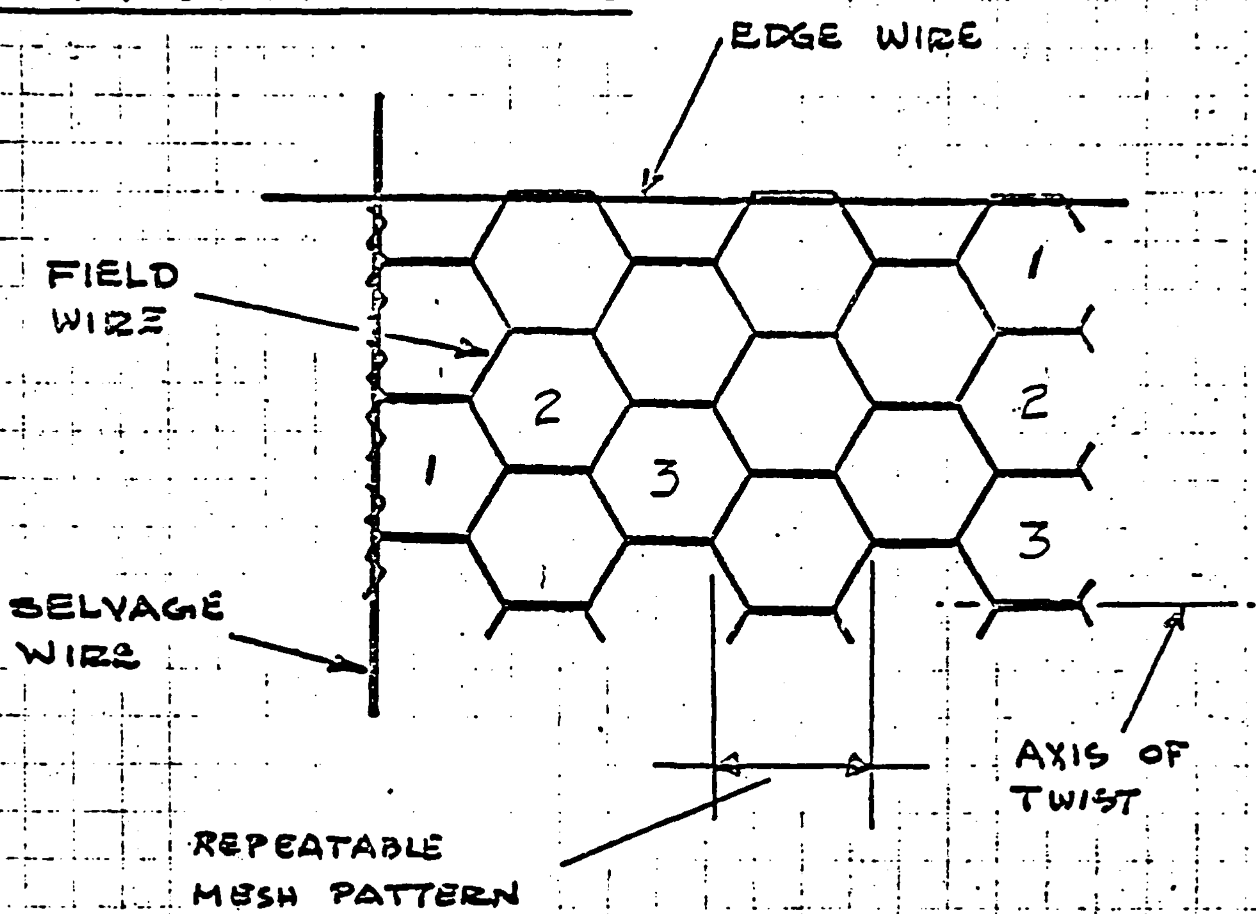


FIGURE 1

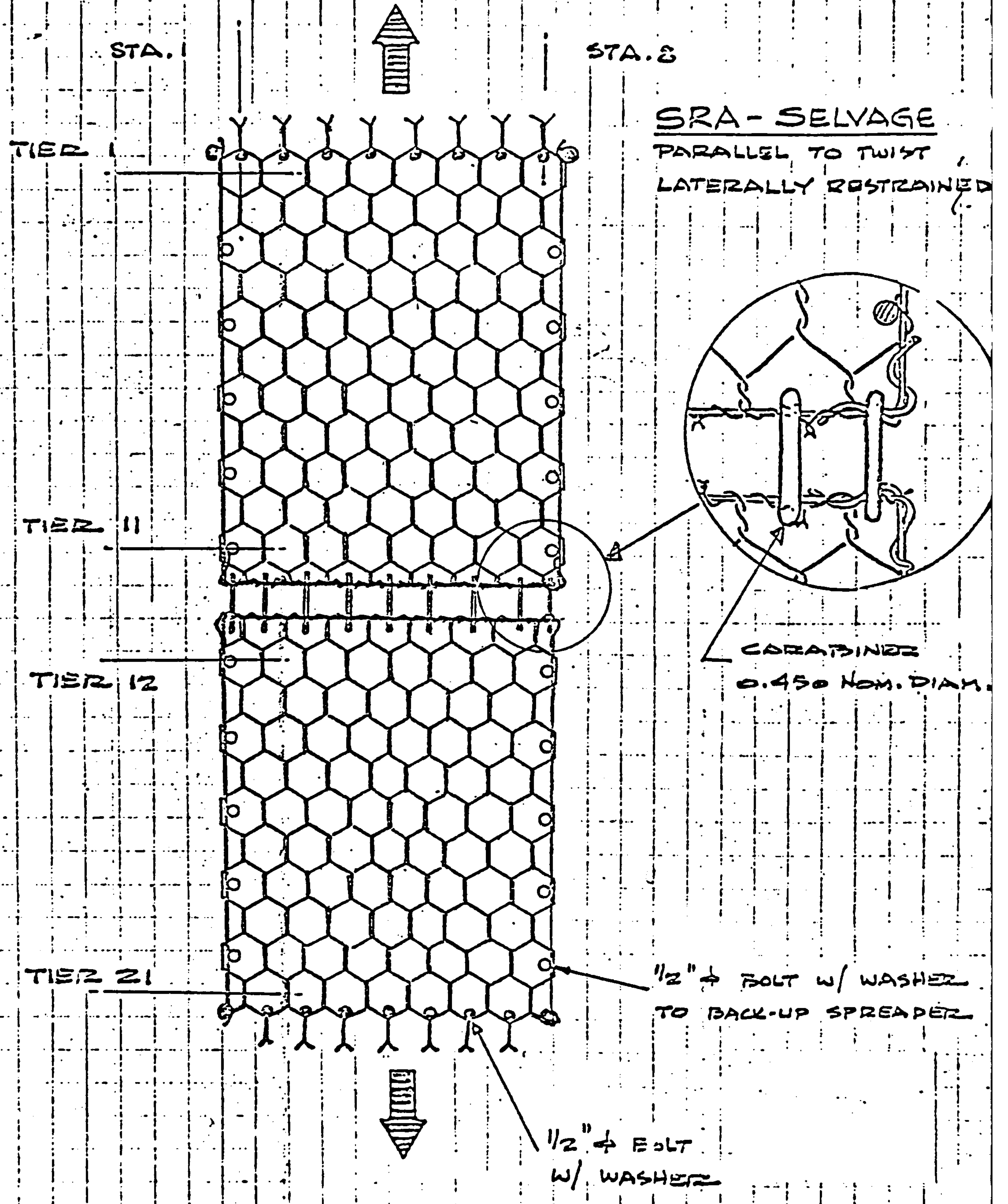
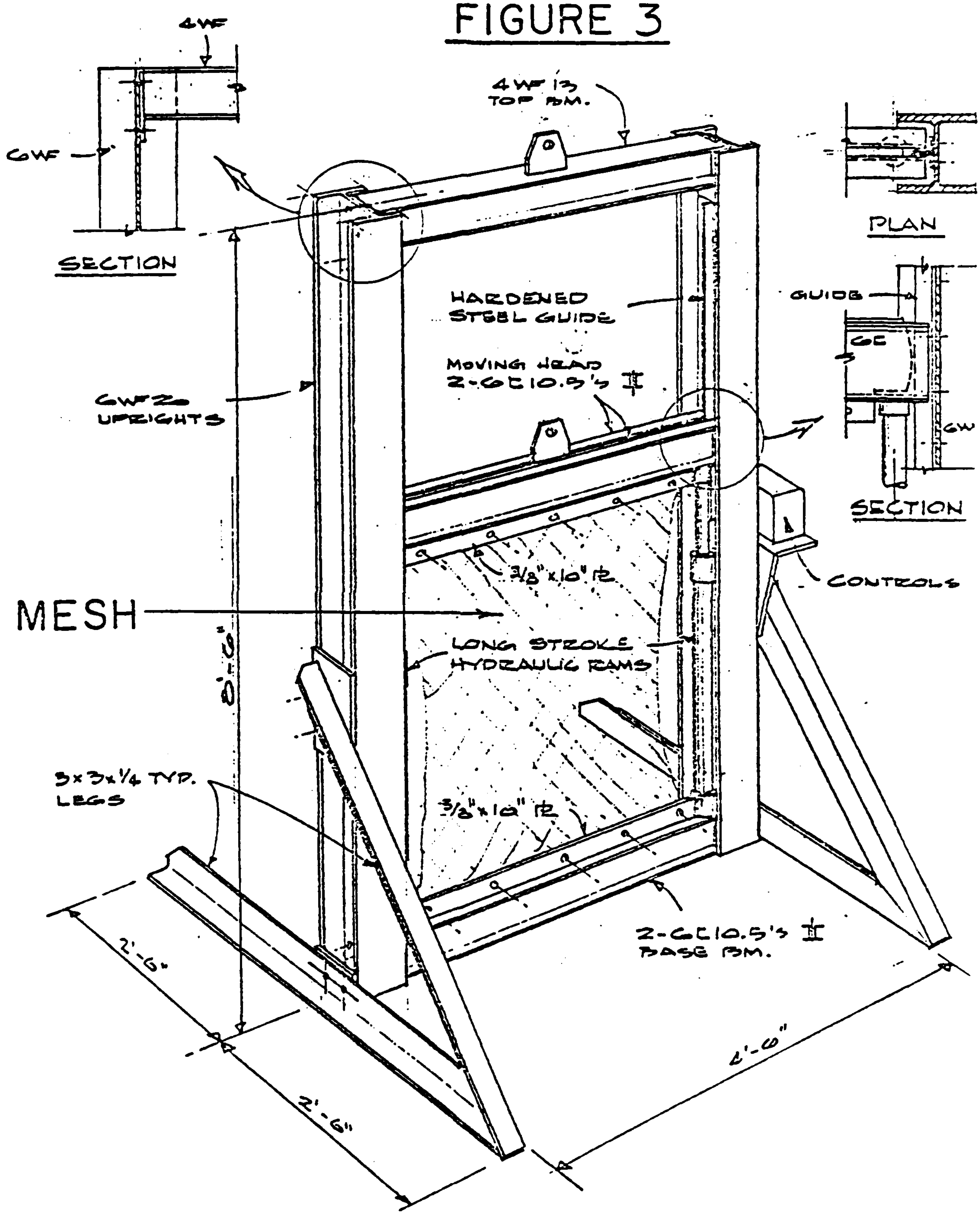

STA. 1
STA. 8
SRA - SELVAGE
PARALLEL TO TWIST
LATERALLY RESTRAINED
TIER 1
TIER 11
TIER 12
TIER 21
CARABINER
0.450 NOM. DIAM.
1/2" ϕ BOLT W/ WASHER
TO BACK-UP SPREADER
1/2" ϕ BOLT
W/ WASHER

FIGURE 2

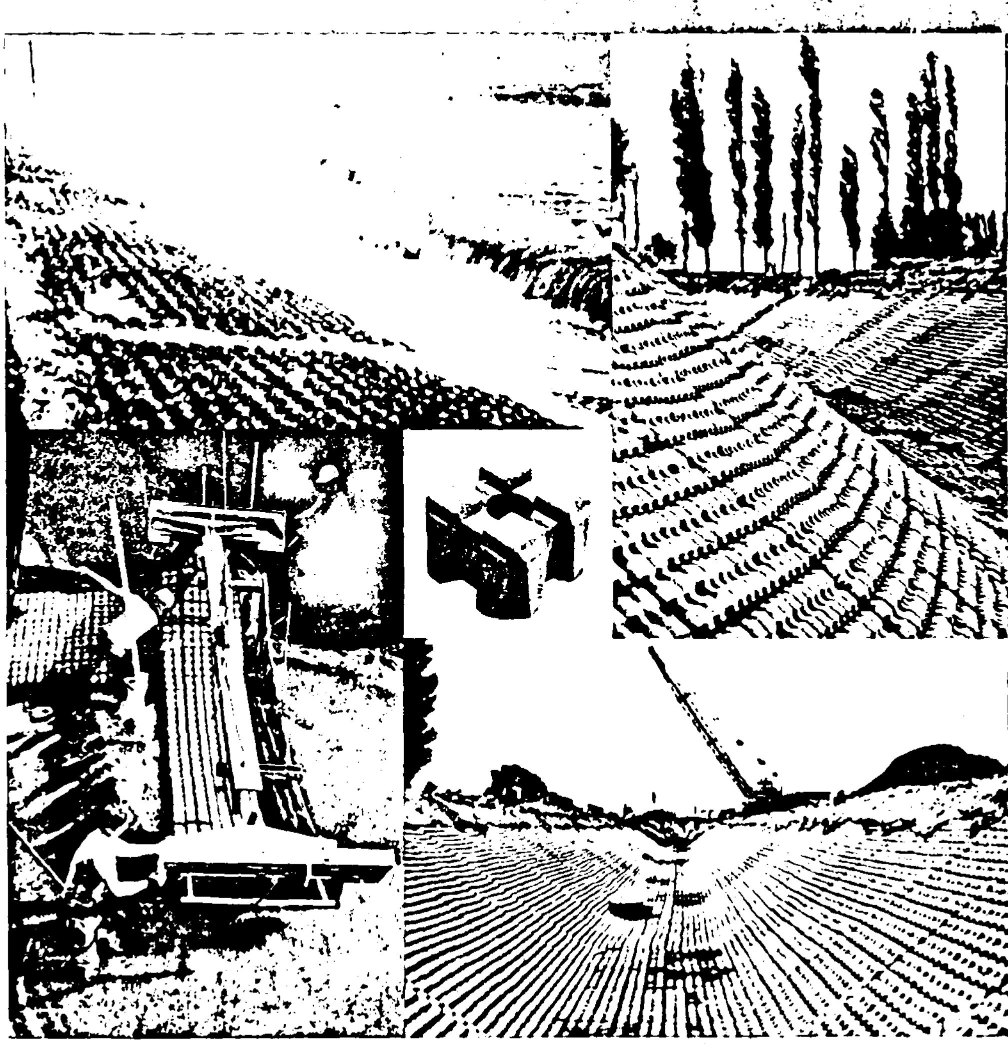
MESH TENSION TESTING MACHINE

FIGURE 3



APPENDIX "B"
ARTICULATED
CONCRETE MATTRESS

Specify **ERO/CON®** precast cellular concrete for erosion control, drainage and other uses.



ERO/CON CORPORATION

:RO/CON® the engineered ılternative.

Ɔ/CON precast cellular concrete provides an engineered alternative for a wide variety of erosion control, drainage and other ;. Its matrix of open cells and projections retain soils, relieve hydrostatic pressure and provide the perfect environment for :olishing natural vegetation.

Ɔ/CON is flexible, conforming to ground contours, settling without fracture, and is installed on level ground without bedding. ıılable either as separate GRIDS or as prefabricated MATS, with individual GRIDS bonded to select filter fabric. ERO/CON upplied and transported from our manufacturing facilities to the job site. The result is stable armor protection designed to ·ıstand high water velocities and wave action with aesthetic and ecological advantages. When your plans and specifications call armor protection; that will stand up to severe applications and climate conditions, with fast installation, unskilled labor, no d poured concrete and low cost area coverage, even underwater – contact us for further information. Our engineers will vide design assistance, on job consultation and installation supervision.

Applications

ərosion control

ᴙO/CON provides defense against erosion in fast flowing creeks, streams and .ers. ERO/CON is particularly suitable for armoring shorelines of coastal .aters, rivers, lakes, reservoirs and other bodies subject to wave action. ERO/ ƆN, with the combined stability of its specially designed grids and filter fabric, ·ovides flexible armor protection undamaged by subsidience and hidden by .ture.

ɹrainage

ᴖO/CON provides an excellent lining for drainage channels. Bed and channel ɳks are stabilized against erosion caused by the tendency of water to change · planned course of a channel.

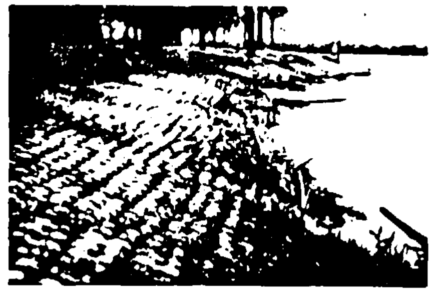
Ɔ/CON aprons at pipe outlets eliminate pipe undercutting that may lead to .ere problems such as surrounding bank failure and siltation downstream. ·ner drainage applications include: ditch linings, spillways, headwalls, sediment .ins and traps, pipe inlet protection, and protection of berms.

ɔther uses

- Bulkheads, in lieu of
- Subaqueous Pipeline Protection
- Slope Protection
- Road Shoulders
- Boat Launching Ramps
- Dike and Levee Protection
- Sloped Headwalls
- Bridge Abutment Protection
- Airport Runway Shoulders
- Secondary Roads
- Overflow Parking Lot
- Pollution Pit Linings

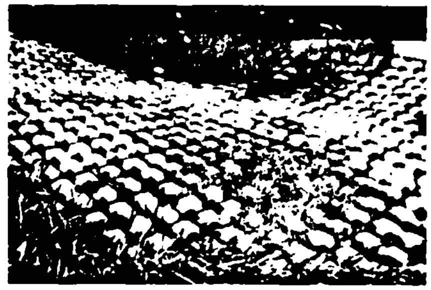
ͻharacteristics

;tability



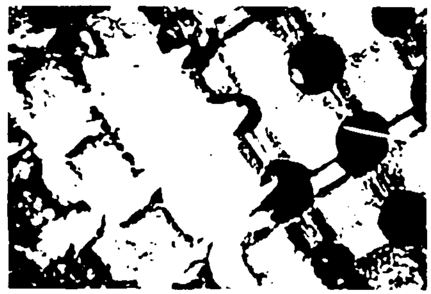
O/CON provides nonerodable armor protection that acts as a single articulat- mattress to withstand destructive forces of water. The proper ERO/CON size l weight is determined by the design velocity or wave height to which it shall subjected.

lexibility



O/CON grids are not interconnected, therefore, they always remain flexible. grids are specially tapered to allow for this flexibility, maintaining minimum ess on the grids. This facility allows ERO/CON to conform to contours even settlement occurs after installation.

iltration

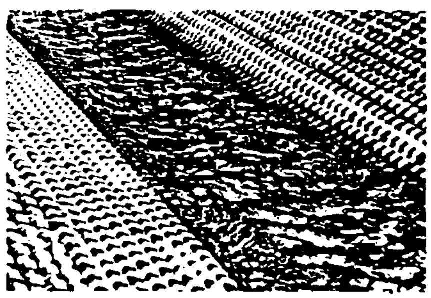


O/CON grids can be separately placed on filter fabric, or bonded to filter ric to form prefabricated mats. Whichever laying system is used, an important nponent of ERO/CON is the filter fabric. Filter fabric replaces graded filter terials for a more simplified system. The permeability of the fabric and grids ieves hydrostatic pressure while its capacity for soil retention prevents leaching materials through the installation.

/egetation

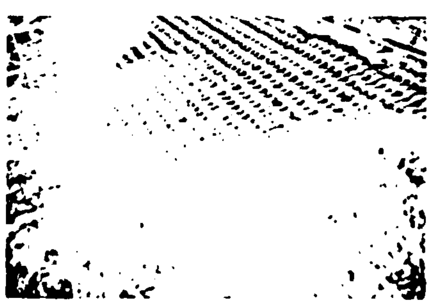
O/CON, with its open cells filled with stone, (d_{50} < .75"), precludes vegeta- cover. When vegetation is desired, the open cells are filled with soil, then wn or planted. ERO/CON provides the perfect environment for the establish- nt of vegetation. Even roots of small shrubs can penetrate the filter, providing permanent anchor for the installation while beautifying the landscape.

low resistance



O/CON'S matrix of open cells and projections create a surface with critical ughness. This surface roughness causes a loss of energy in turbulant flow, due the formation of wakes within each open cell, thus reducing the potential for sion. The ERO/CON Manning Roughness Coefficient, "n", has a value ging from 0.03-0.05, depending on the grid size, material filling the open s and vegetative cover.

vave run-up

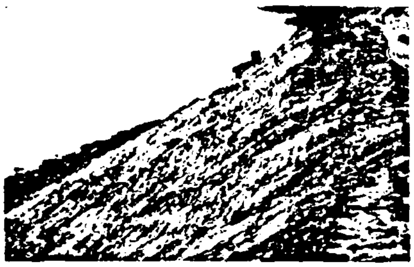


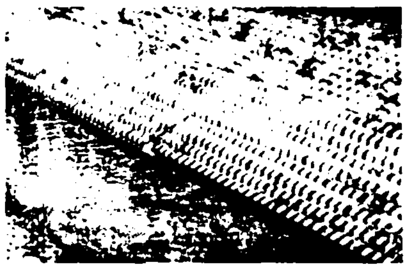
O/CON, because of its special design, reduces wave run-up by as much as , compared to smooth surfaces. This feature allows the design engineer to uce the height of the installation, thus reducing the required area of pro- tion with substantial savings of armor materials.

Advantages

- ECONOMICAL
- EASY TO INSTALL, EVEN UNDERWATER
- NO SKILLED LABOR REQUIRED
- AVAILABLE IN SIX CLASSES, TO MEET VARIOUS HYDRAULIC REQUIREMENTS
- AVAILABLE AS MACHINE PLACED MATS OR HAND PLACED GRIDS
- CAPABLE OF WITHSTANDING HIGH WATER VELOCITIES
- CAPABLE OF WITHSTANDING WAVE ACTION
- FLEXIBLE, CONFORMS TO GROUND CONTOURS AND SETTLES WITHOUT FRACTURE
- NO BEDDING
- MINIMUM EXCAVATION
- NO FIELD POURING OF CONCRETE
- MANUFACTURED UNDER IDEAL PLANT CONDITIONS
- HIGH STRENGTH CONCRETE
- LOW ABSORPTION RATE
- ELIMINATES LEACHING OF SUBSOILS
- FOSTERS NATURAL VEGETATION OF SLOPES, BANKS AND GRASS/PAVED AREAS
- CONSISTANT ATTRACTIVE TEXTURE
- UNIFORM INSTALLATION OF CONSISTANT QUALITY
- CAPABLE OF HIGHWAY LOADINGS
- SAFE SURFACE FOR PEDESTRIANS AND VEHICLES
- RESISTANT TO SEAWATER AND ROAD SALTS
- UP TO 1280 SQ. FT. PER TRAILER LOAD
- MINIMUM ACCESS REQUIREMENTS

Example Applications


RIVER BANK

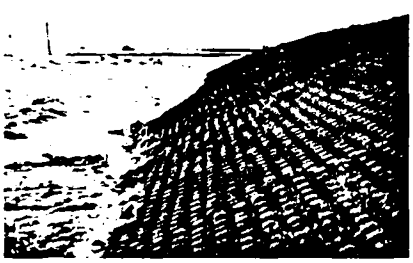

DRAINAGE CHANNEL


ROAD SHOULDER

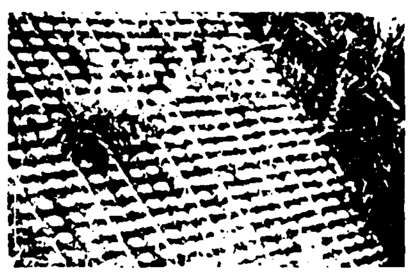

LAKE SHORELINE

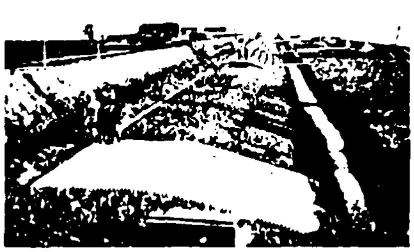

DRAINAGE CHANNEL

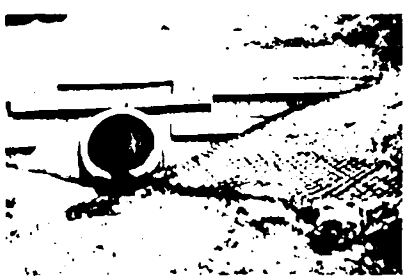

BOAT LAUNCHING RAMP

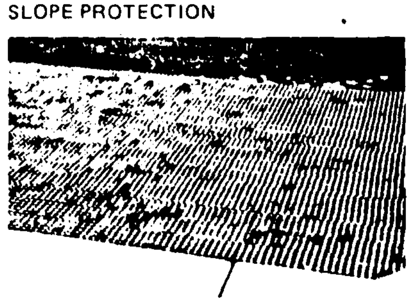

COASTAL SHORELINE


DRAINAGE CHANNEL


SLOPE PROTECTION


HARBOR EXPANSION


OUTLET PIPE

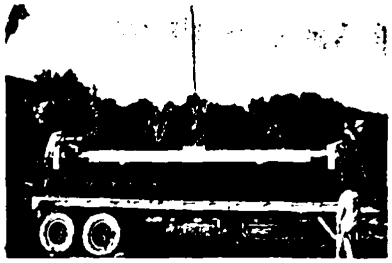

AIRPORT RUNWAY SHOULDER

Handling & Installation

Site preparation

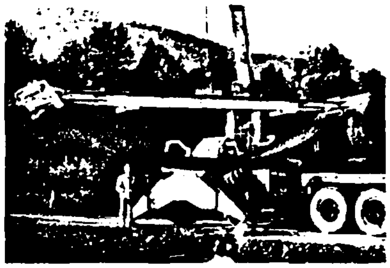
It is necessary to trim an area to be protected by ERO/CON to ensure neat effective ...ts and smooth contours. Obstructions, such as roots and projecting stones, are ...moved. Holes, soft areas and large cavities are filled and compacted with suitable ...terial. Minor irregularities are accommodated by the flexibility of ERO/CON. ...e angle of repose of natural soil cannot be exceeded. Excavation for toe, flank, ...per bank protection and failure cutoffs are done in accordance to each specific ...sign.

Delivery



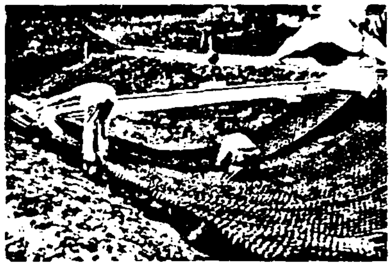
...RO/CON is delivered on trailers with MATS stacked as shown and GRIDS palletized. ...ailers are positioned for direct unloading and setting. Where staging of MATS is ...esired, ground should be cleared to allow for level stacking.

Handling



...RO/CON MATS are lifted by a boom, fitted with special clamps, as shown, available ...om your ERO/CON supplier. The clamps grip the filter fabric flap at each end of ...e mat. The lifting boom may be handled with any convenient device, including ...ranes or backhoes.

Placement

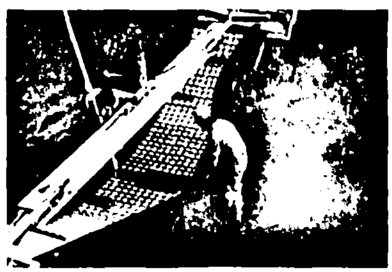


...RO/CON MATS can be laid side by side and/or end to end overlaying the filter fabric ...ap of the previously laid mat. Each mat has a centralizing mark to be used for the ...entering of the next mat.

Bends

...hen bends are of a large radius, mats are placed by easing the outer edges. In the case ... sharper bends, gusset pieces are made to required shapes by "pealing off" blocks ...om standard mats. Caution should be exercised to ensure that adequate overlapping ... filter fabric flaps is allowed, when in doubt install filter fabric gussets.

Laying ERO/CON underwater

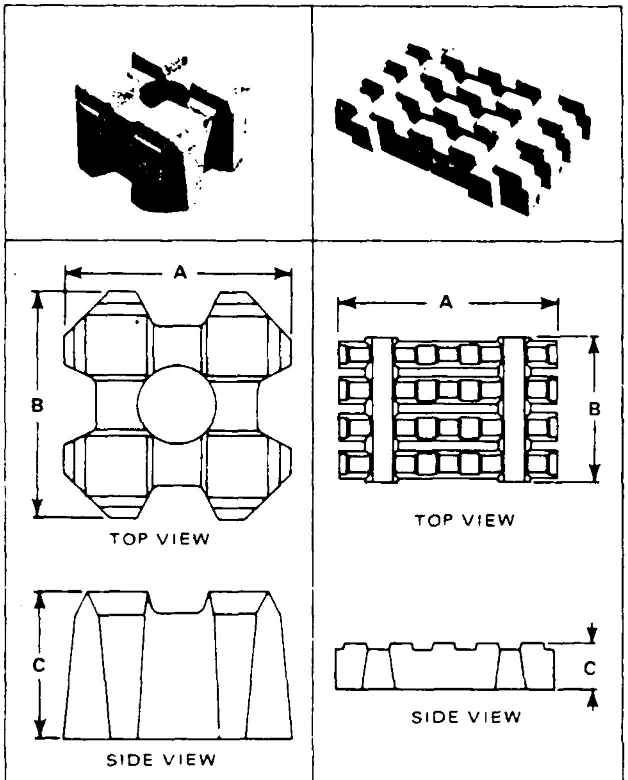


...O/CON MATS can be easily installed underwater. Care should be exercised to ...sure that the filter fabric flaps do not float before the adjacent mat is placed. To ...ake certain that the mats are laid abutting each other, a pole is placed against the ... of the previously laid mat. The next mat is guided into place, following the pole, ...uring no gaps are left in the installation. The poles and special cable attachments ... underwater release of the clamps are supplied with each boom.

...RO/CON CORPORATION

Dimensions & Weights

ERO/CON® Grids

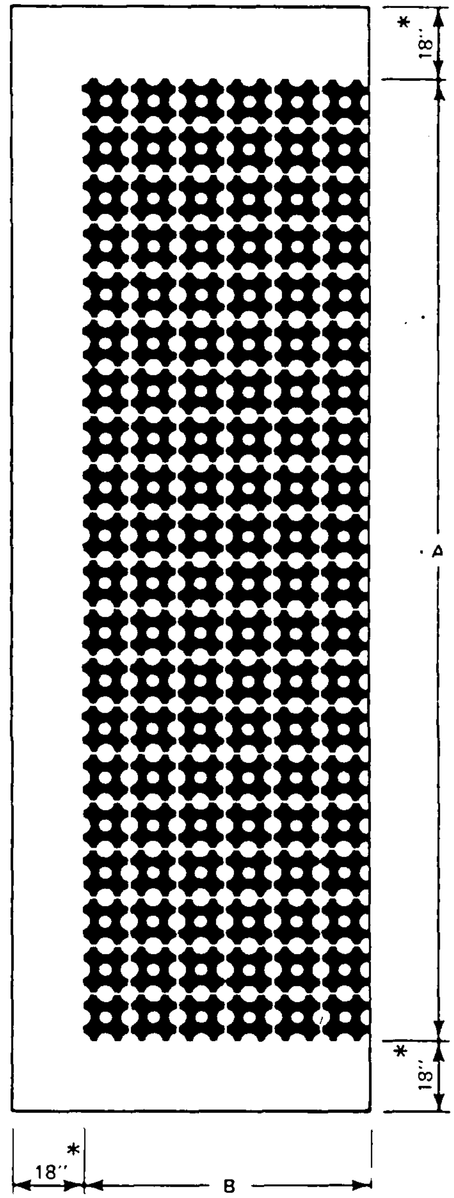


CLASS 64S, 64H
256S & 256H

CLASS
384S & 384H

TABLE 1.0		
ERO/CON TECHNICAL DATA — CLASS	64 S, 256 S & 384 S	64 H & 256 H & 384 H
SPECIFIC WEIGHT (γ), LBS. / CU. FT.	130 140	160-170
COMPRESSIVE STRENGTH, LBS./SQ. IN.	4000 5000	5000 6000
ABSORPTION, %	8	8
FREEZE THAW	NO VISIBLE EFFECT	

ERO/CON® Mats



*FILTER FABRIC FLAPS FOR CONTINUOUS FILTER OVERLAPPING AND HANDLING

TABLE 2.0

ERO/CON GRIDS

CLASS	NOMINAL DIMENSIONS			GROSS AREA/ GRID SQ. FT.	WEIGHT/ GRID LBS.	WEIGHT/ SQ. FT. LBS.	OPEN AREA
	A	B	C				
64S	8"	8"	5"	0 44	15 16	34 1 36 4	35%
64H	8"	8"	5"	0 44	18 19	40 9 43 2	35%
256S	16"	16"	10"	1 77	120 130	67.8 73 4	35%
256H	16"	16"	10"	1.77	140 150	79 1 84 7	35%
384S	24"	16"	4¼"	2 67	90 95	33 8 35 7	20%
384H	24"	16"	4¼"	2 67	108 113	40 5 42 3	20%

TABLE 3.0

ERO/CON MATS

CLASS	DIMENSIONS, FT.		SQ. FT./ MAT	GRIDS MAT	WEIGHT/ SQ. FT. LBS.	MAX. WEIGHT/ MAT LBS.
	A (max.)	B				
64S	20	4	80	180	34 1 36 4	2912
64H	20	4	80	180	40 9 43 2	3456
256S	12	4	48	27	67 8 73 4	3523
256H	12	4	48	27	79 1 84 7	4066
384S	NOT AVAILABLE IN MATS					
384H	NOT AVAILABLE IN MATS					

ERO/CON 256

Weight (average)	125.0 lbs.
Area	166.4 sq. in., or 1.156 sq. ft.
Specific Weight (average)	137.1 lbs./cu. ft.
Weight Immersed (average)	72.6 lbs.
Absorption (average)	4.05 %

Maximum Permissible Tractive Force:

The permissible tractive force is the maximum unit tractive force that will not cause erosion of the material forming the channel bed on a level surface with uniform flow.

Solving for the unit tractive force T_L that causes impending motion on a level surface,

$$T_L = (W_s/a) \tan \theta$$

where W_s is the immersed weight of the material, "a" is the effective area of the material particle, and θ is the angle of repose of the material.

Calculation:

Assume the angle of repose for ERO/CON 256 is 33.7°.

$$T_{L64} = (W_s 256S/a_{256S}) \tan 33.7^\circ$$

$$T_{L64} = (256S/256S) \tan 33.7^\circ \, (72.6/1.156)$$

$$T_{L64} = (62.8)\,(0.67)$$

$$T_{L64} = 42.1 \text{ lbs./sq. ft.}$$

Solving for the unit tractive force T_S that causes impending motion on sloping side bank,

$$T_S = T_L K$$

where K is the tractive force ratio.

Calculation:

$$K = \left[1 - \frac{\sin^2 \phi}{\sin^2 \theta}\right]^{1/2}$$

Side Slope: 1 on 3, 1 on 2, 1 on 1 1/2 and 1 on 1

$$K_{18.4^\circ} = \left[1 - \frac{\sin^2 18.4}{\sin^2 33.7}\right]^{1/2} = .82 \qquad {}^*K_{33.7^\circ} = \left[1 - \frac{\sin^2 33.7}{\sin^2 35.0}\right]^{1/2} = .26$$

$$K_{26.6^\circ} = \left[1 - \frac{\sin^2 26.6}{\sin^2 33.7}\right]^{1/2} = .59 \qquad {}^*K_{45.0^\circ} = \left[1 - \frac{\sin^2 45.0}{\sin^2 46.0}\right]^{1/2} = .18$$

*For 1 on 1 1/2 and 1 on 1 side slopes, ERO/CON mats are pinned and angle of repose is increased.

$$T_{S64_{3:1}} = T_L K_{18.4^\circ} = (42.1)\ (.82) = 34.5 \text{ lbs./sq. ft.}$$

$$T_{S64_{2:1}} = T_L K_{26.6^\circ} = (42.1)\ (.59) = 24.8 \text{ lbs./sq. ft.}$$

$$T_{S64_{1\ 1/2:1}} = T_L K_{33.7^\circ} = (42.1)\ (.26) = 10.9 \text{ lbs./sq. ft.}$$

$$T_{S64_{1:1}} = T_L K_{45.0^\circ} = (42.1)\ (.18) = 7.6 \text{ lbs./sq. ft.}$$

PART 1: GENERAL

1.01 SCOPE OF WORK

A. The contractor shall furnish all labor, materials, equipment, and incidentals required and perform all operations in connection with the installation of cellular concrete erosion control grids as shown on the Contract Drawings and as specified herein.

PART 2: PRODUCTS

2.01 MATERIAL

A. General. All cellular concrete grids shall be premanufactured with specific hydraulic capabilities and placed on plastic filter fabric. The sources from which the contractor proposes to obtain the material will be selected well in advance of the time when the material will be required in the work. Suitable samples of the cellular concrete grids and filter fabric shall be submitted to the engineer for approval, prior to delivery of any such material to the site of the work. Unless otherwise specified, all test samples shall be obtained by the contractor and delivered at his expense to a point designated by the engineer at least sixty (60) days in advance of the time when the placing of the cellular concrete mat protection is expected to begin.

B. Cellular Concrete Grids

1. Quality. Suitable tests will be used to determine the acceptability of the cellular concrete grids. In the event suitable test reports, that are satisfactory to the engineer, are not available, as in the case of newly operated sources, the material shall be subjected to such tests as are necessary to determine its acceptability for use in the work. Tests to which the materials may be subjected, include specific gravity, absorption, compression, and such other tests as may be considered necessary to demonstrate to the satisfaction of the engineer that the materials are acceptable for use in the work. All tests will be made by or under the supervision of the City and at its expense.

The cellular concrete grids shall be machine-made by a vibration and compression process, composed of approved and graded aggregates and a no slump concrete mix. The mix water used shall be clean, fresh, free from oil, acids, soluable salts and organic impurities. Cement shall conform with ASTM 150 requirements (Portland Cement). All concrete must be consolidated and steam cured.

Cellular concrete grids must meet the following minimum requirements:

Compressive Strength	5000 P.S.I.
Water Absorption	5% Maximum
Freeze Thaw Test (50 cycles)	No Visible Effect

2. Shape of cellular concrete grids. The grids will be ERO/CON 384, as shown on the Contract Drawings. They will be comprised of open cells and projection heights and have the following physical characteristics:

	Overall Grid Size	Projection Heights	Percent of Open Area	Weight/Grid
ERO/CON 384	23 1/8" x 15 5/8" x 4 3/4"	3/4"	33 - 37	90 - 100 lbs.

3. Plastic filter fabric. The filter fabric shall be manufactured woven, mechanically, linked, polyethylene, polypropylene or isotropic polyester. The filter fabric shall be resistant to all chemicals in strengths normally encountered in natural water and soil conditions. Selection of filter fabric shall be made by the supplier of the cellular concrete grids in accordance to a gradation analysis of the soil and/or fill material on which that grids are to be placed. The filter fabric must meet the following minimum requirements:

Tensile Strength (lbs./in.)	ASTM D 1682	
	Warp	200
	Fill	240
Bursting Strength (P.S.I.)	ASTM D 751	500
Puncture Strength (lbs.)	ASTM D 751	120
Equivalent Opening Size (U.S. Standard Sieve Size)		70 - 40
Percent Open Area		25 - 30
Permeability (10^{-3}m/sec.) (Surface Area $10cm^2$) (Static Water Pressure 10 cm)		65
Elongation %		20 - 30
Weight (oz. per sq. yd.)		7 - 8

4. Manufacturer. Cellular concrete grids shall be "ERO/CON" by Soil Stabilization, Inc. 45 S. Main St. - West Hartford, CT or approved equal.

PART 3: EXCAVATION

3.01 FOUNDATION PREPARATION

A. Areas on which cellular concrete grids and filter fabric are to be placed shall be shaped to conform to cross sections shown on the Contract Drawings within an allowable tolerance of plus or minus 3 inches from the theoretical side slopes and grades. Where such areas are below the allowable minus tolerance limit, they shall be brought to grade by filling with select material and compacted. All obstructions, such as roots and projecting stones, must be removed. Immediately prior to placing the filter fabric and cellular concrete grids, the prepared base will be inspected by the engineer and no filter fabric or grids shall be placed thereon, until that area has been approved.

Excavation for toe, terminals, upper bank protection and failure cutoffs, shall be done in accordance to each specific design outlined in the Contract Drawings.

3.02 PLACEMENT OF CELLULAR CONCRETE GRIDS

A. General. Cellular concrete grids, as specified in paragraph 2.01 B of this Section, shall be placed within the limits shown on the Contract Drawings.

B. Placement. The cellular concrete grids and filter fabric shall be placed on the Select Borrow in such a manner as to produce a level surface, and shall be constructed within the specified tolerance to the lines and grades shown on the Contract Drawings. A tolerance of plus 3 inches or minus 3 inches from the slope lines and grades shown on the drawings will be allowed in the finished surface of the cellular concrete grids, except that either extreme of such tolerance shall not be within 20 feet of each other and shall not be continuous over an area greater than 200 square feet.

The cellular concrete grids shall be installed side by side and/or end to end, so that the grids abut each other.

When placing the cellular concrete grids at bends, it will be necessary to ease grids apart for the purpose of shaping to a required contour.

The manufacture of the cellular concrete grids shall supply the engineer and contractor with a laying schedule.

1. Pegging. Where called for in the Contract Drawings, peg grids to the side slopes. Use 3/4" reinforcing bars as shown in the Contract Drawings.

2. Finishing. The open cells of the cellular concrete grids should be backfilled with gravel or crushed stone. $d_{50} < .75$ in., in areas below the low water line and with soil in areas above the low water line. The level of fill should be 3/8" below the top of the cellular concrete grids.

3. Consultation. The manufacturer of the cellular concrete grids shall provide on job consultation.

APPENDIX "C"
WOVEN FILTER CLOTH

Geosynthetics And Their Use In Filtration And Drainage Applications

By Robert M. Koerner

Abstract

Geosynthetics, a generic term for geotextiles, geogrids, geomembranes, geocomposites are described, along with a conceptual outline of the available methods used to design with these materials. When using a "design by function" concept it is seen that five basic functions are available. These are separation, reinforcement, filtration, drainage and moisture barrier. In this particular paper, designs involving filtration (cross-plane fabric flow) and drainage (in-plane fabric flow) are presented. This latter case will serve to extend geotextiles into the area of geocomposites.

Overview Of Geosynthetics

The development of geosynthetic materials are proceeding at an incredibly fast pace. While they differ widely in appearance, use and function they invariably seem to be used in connection with soil or rock (hence, the prefix "geo") and are almost entirely made from manmade materials (hence, "synthetic"). Thus, within the generic heading of "geosynthetics" easily can be placed geotextiles (permeable fabrics), geogrids (open net-like plastics), geomembranes (impermeable polymer sheets), and geocomposites (combinations of the above or geosynthetics with other materials). The title furthermore leaves the door open toward other related systems that may be developed in the future.

Possible Design Methods

The original geotextiles available were often produced on a mass per unit area basis ranging form light to heavy. Since properties (mainly the strength and hydraulic related ones) were directly proportional, one could enter into a cost design by purchasing the "best" geotextile available within an allocated budget. Such simplistic days are over, however, and currently two different design routes have emerged.

Design by Specification

"Design by specification" is very common and is used almost exclusively when dealing with public agencies. In this method several categories of end use are listed along with a number of critical fabric properties. Usually minimum values are listed. Those geotextiles available are then checked for their corresponding minimum properties (not average lot, nor average roll values) and compared to the specification value. If several geotextiles are found to be adequate, the final choice is usually made on the basis of least cost.

Design by Function

"Design by function" consists of identifying the primary function that the fabric will be asked to serve and then, using geotechnical engineering concepts and principles, calculating the required value for the particular property relating to that function. This required value is then compared to the minimum value of the candidate geotextile which allows for the calculation of a factor of safety. If sufficiently high, that particular geotextile is suitable. If other fabrics are also adequate, the decision is then made on the basis of least cost. Since the design by function method utilizes the complete spectrum of geotechnical engineering methods to calculate the required geotextile property or properties, its appeal is naturally oriented toward such firms and individuals with this expertise. It is, however, a rational approach which can be openly viewed as to its methods and procedures. It is the method of choice by the writer and will be used in this paper.

Functions And Mechanisms

In the "designing by function" method one must assess the given application and describe what is the primary function of the geosynthetic material to be used. The choices are between separation, reinforcement, filtration, drainage and moisture barrier. A few comments are offered in each of these categories:

Separation is required when a geosynthetic (usually a geotextile or a geomembrane) is placed between two dissimilar materials to avoid their mixing. Examples are placement on subgrade soil beneath pavement systems, or in earth dams to separate differently zoned soils, or as barriers to prevent general mixing. Material properties of major concern are strength, burst resistance and tear resistance.

Reinforcement is involved when the geosynthetic (usually a geotextile or a geogrid) is placed in tension within a soil or rock system. Examples are beneath unpaved roads on soft subsoils, for soil or rockfilled walls systems and in reinforced embankments and slopes. Different mechanisms are involved which vary from membrane type tension, to shear mobilized tension and even to anchorage or pullout developed tension. Material properties which result from the appropriate analysis are required modulus, strength, elongation and creep resistance. *See* GFR *Vol. 3, No. 2 for a review on reinforcement, Editor.*

Filtration using geosynthetics (usually geotextiles) occurs when water is passing from one side of the material to the other. In such cases the fabric is required to allow unimpeded flow (i.e., not to develop excess pore water pressures), yet to simultaneously prevent soil loss from the upstream side of the geotextile. Examples are geotextiles wrapped around porous pipe under-drains or stone aggregate drains, fabric silt fences and silt curtains, geotextiles placed behind flexible walls and temporary sheeting. The geotextile properties resulting from the design are the required cross-plane permeability (actually the permittivity) and the fabric void opening, size (apparent opening size, AOS; equivalent opening size, EOS).

Drainage using geosynthetics (usually geotextiles or geocomposites) occurs when water is flowing in the plane of the material. As with filtration, adequate flow along with proper soil retention are required. Examples are conducting water within and out of earth dams, beneath embankments and from behind permanent retaining walls and basements. Resulting from the design procedures are the required in-plane permeability (actually the transmissivity) and the fabric void opening size, the AOS.

Moisture Barrier in geosynthetics is possible when one impregnates a geotextile with bitumen or polymer, or with a geomembrane. Also certain geocomposites can perform in this manner. ... mples are in crack reflection over... nd membrane encapsulated soil (MESL's) for impregnated geo...es, and as pond liners, covers, small dams, water stops for geomembranes. Design is oriented around the amount of vapor transport which occurs over a given time period and its effect on the behavior of the internal system.

Selected Filtration Designs

Filtration Concepts—Before illustrating a few specific design procedures, some design concepts are necessary. In considering adequate flow, the geotextile's permittivity will be used. It is defined as follows:

$\psi = k_n / t$

where

ψ = permittivity

k_n = permeability coefficient normal to the fabric

t = fabric thickness

Regarding soil retention, the design guide of Table 1 will be used to determine the geotextile's apparent (or e...lent) opening size, AOS. It is ... be a function of the retained soil density and gradation. (Note that O_{95} is the opening size in mm equivalent to the AOS or EOS sieve number which corresponds closest to it)

Table 1—Relationships Used to Obtain Fabric Opening Size to Prevent Excessive Soil Loss

Relative Density	$1 < CU < 3$	$CU > 3$
Loose ($D_R < 50\%$)	$O_{95} < (CU)(d_{50})$	$O_{95} < (9\ d_{50})/CU$
Intermediate ($50\% < D_R < 80\%$)	$O_{95} < 1.5\ (CU)(d_{50})$	$O_{95} < (13.5\ d_{50})/CU$
Dense ($D_R > 80\%$)	$O_{95} < 2\ (CU)(d_{50})$	$O_{95} < (18\ d_{50})/CU$

where

d_{50} = soil particle size corresponding to 50% finer

CU = coefficient of uniformity ($= d_{60}/d_{10}$)

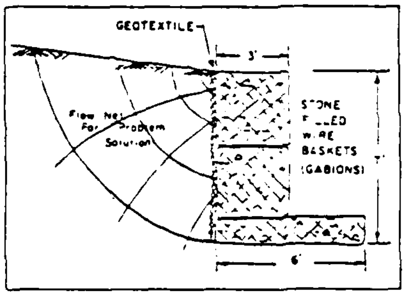
d_{10} = soil particle size corresponding to 10% finer

d_{60} = soil particle size corresponding to 60% finer

O_{95} = apparent opening size of geotextile (if data is not given by manufacturer this value is approximately the AOS sieve value in mm)

Geotextile Design Behind Gabion Wall[2]

Problem: Given a 7′ high gabion wall consisting of 2–3′ × 3′ × 12′ baskets siting on a 6′ × 1′ × 12′ mattress is shown below. The backfill soil is a medium dense silty sand of d_{10} = 0.03 mm, d_{50} = 0.07 mm, CU = 2.5; k = 3.3 × 10^{-3} ft/sec and D_R = 70%. Check the adequacy of three candidate geotextiles whose properties will be given later in the problem.



Solution: The design is in two stages with the first being a determination of the required flow capability of the geotextile. This is done by calculating the required permittivity, $\psi = k/t$.

(a) Calculate the actual flow rate using a flow net as shown

$$q = k\ h\ (F/N)$$
$$= (3.3 \times 10^{-3})(7)(4/4)(1.0)$$
$$= 0.231\ \text{ft}^3/\text{sec}$$

(b) Calculate the required permittivity using Darcy's formula

$$q = k\ i\ A;$$

$$q = k \frac{\Delta h}{t} A$$

$$\frac{k}{t} = \frac{q}{(\Delta h)(A)}$$

$$\psi_{reqd} = \frac{0.231}{(7)(7 \times 1)}$$

$$\psi_{reqd} = 0.47 \times 10^{-2}\ (\text{sec}^{-1})$$

(c) Check against actual permittivity of the available geotextiles. (k_n and t values are found in commercial literature).

Chart 1.

Property \ Geotextile	#1 needled nonwoven	#2 woven monofilament	#3 heat set nonwoven
k_n (in sec)	0.118	0.014	0.008
t (in)	0.060	0.030	0.015
ψ_{act} = k/t (sec⁻¹)	2.0	0.47	0.53
F.S. = ψ_{act}/ψ_{reqd}	420	100	110

Easily seen in Chart 1 is that all the geotextiles are adequate to handle the required flow.

The second part of the design relates to the fabric's opening size in order to prevent soil loss.

(d) The appropriate criterion for opening size must first be selected. For the set of conditions in this problem, Table 1 results in the following:

$$O_{95} < 1.5\ (CU)(d_{50})$$
$$< 1.5\ (2.5)(0.07)$$
$$O_{95} < 0.26\ \text{mm}$$

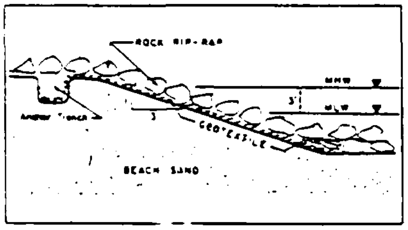
The closest comparable sieve size is the #60 which has 0.25 mm openings, thus AOS values of higher numbered sieves are acceptable.

(e) Check against actual AOS values:
Fabric #1, AOS = #100 (= 0.15 mm) OK.
Fabric #2, AOS = #70 (= 0.21 mm) OK, but barely

Fabric #3, AOS = #100 (= 0.15 mm) OK.

Geotextile Design Beneath Rock Rip-Rap[2]

Problem: Evaluate the filtration adequacy of a candidate geotextile for placement beneath a rock rip-rap erosion control system in a coastal area with 3' tides as shown in the following sketch. The geotextile properties are k = 0.010 in/sec, t = 35 mils and AOS = #70. The in-situ soil is a beach sand (SP) with d_{10} = 0.12 mm; d_{50} = 0.37 mm CU = 3.5; in a medium dense condition D_R = 75% at a porosity of 0.40.



Solution: As with all filtration designs this is a two part problem, one for adequate flow and the other for soil retention. For adequate flow, the procedure is as follows:

(a) Estimate the maximum flow rate due to the three-foot tidal lag. With the tide receding at a maximum rate during an initial 0.5 hour period, then an approximate value (assuming a 300' triangular zone) is:

$$q_{max} = \frac{300 \times 3 \times 1}{2} \times \frac{0.4}{0.5}$$
$$= 360 \text{ ft}^3/\text{hr}$$
$$= 0.100 \text{ ft}^3/\text{sec}$$

(b) Calculate the required permittivity using Darcy's formula

$$q = k\,i\,A$$
$$= k \frac{\Delta h}{t} A$$
$$\frac{k}{t} = \frac{q}{\Delta h\ A}$$
$$= \frac{0.100}{(3.0)(9.48 \times 1)}$$
$$\psi_{reqd} = 0.00352\ (\text{sec}^{-1})$$

(c) Since the candidate geotextile has a permeability coefficient of 0.010 in/sec and is 35 mils thick, the actual permittivity is:

$$\psi_{act} = \frac{k_n}{t} = \frac{0.010}{0.035}$$
$$\psi_{act} = 0.29\ (\text{sec}^{-1})$$

(d) The factor of safety is then:

$$FS = \frac{\psi_{act}}{\psi_{reqd}} = \frac{0.29}{0.00352}$$

FS = 82, which is very adequate even considering that a large portion of the fabric will be covered by rock rip-rap. In this case the minimum F.S. should be 10.

The geotextile is now evaluated with respect to its adequacy to retain the soil beneath it.

(e) Using the design chart of Table 1,

$$O_{95} < 13.5\ d_{50}/CU$$
$$O_{95} < (13.5)(0.37)/3.5$$
$$O_{95} < 1.43 \text{ mm}$$

This is equivalent to a #16 sieve which has openings of 1.19 mm.

(f) Check this against the AOS of the candidate geotextile.

$$AOS_{act} = \#70\ (= 0.210 \text{ mm})$$

which is sufficiently tight so that loss of soil will not occur, thus the geotextile is proper as far as filtration is concerned.

Selected Drainage Designs

Drainage Concepts—As with filtration, drainage designs require adequate flow and soil retention. In considering adequate flow, the geotextile cross plane flow, or transmissivity, will be used.

$\theta = k_p t$

where

θ = transmissivity

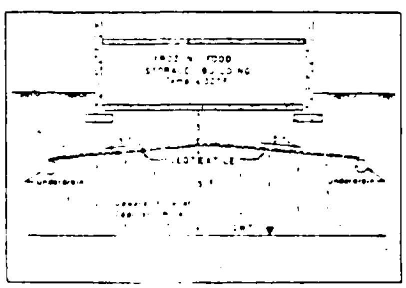
k_p = permeability coefficient in the plane of the fabric

t = fabric thickness

Regarding soil retention, the same guide as given in Table 1 for filtration can be used.

Geotextile Design of a Seepage Cutoff[2]

Problem: Given a storage building for frozen foods which is to be founded as shown below. As a capillary break beneath the building's foundation a geotextile is being considered. Will a 20 oz/yd² needled nonwoven having a transmissivity θ = 0.018 ft³/min-ft at 900 psf normal stress be adequate using a FS = 3.0?



Solution: In stages, the following procedure can be used:

(a) Determine the flow rate of upward water migration to the geotextile. This is a function of the soil's permeability and the thermal gradient drawing the water upward. Guides are given in various references where a conservative value is selected for this problem.

$$q = 5 \times 10^{-4} \text{ ft}^3/\text{min}$$

(b) Calculate the gradient of flow in the geotextile.

5% slope = 0.050

(c) Calculate the required transmissivity, θ_{reqd}, using Darcy's formula.

$$q = k\,i\,A$$
$$= (k\,i)(t \times w)$$
$$kt = q/(i \times w)$$
$$\theta_{reqd} = \frac{0.0005}{(0.050)(1.0)}$$
$$= 0.010 \text{ ft}^3/\text{min-ft}$$

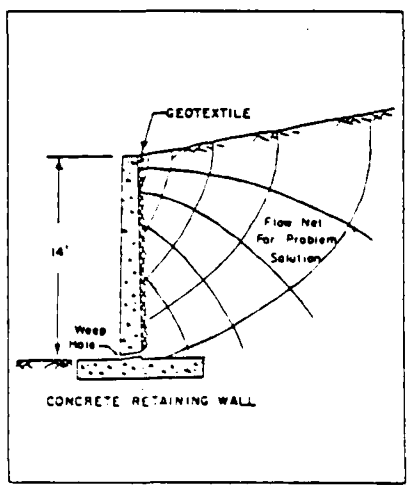
(d) Determine the factor of safety (FS).

$$FS = \frac{\theta_{act}}{\theta_{reqd}}$$
$$= \frac{0.018}{0.0102}$$
$$FS = 1.8 < 3.0 \text{ No Good}$$

Therefore, a thicker geotextile having a θ = (0.010)(3) = 0.030 ft³/min-ft is required, or use multiple layers (in this case two) of the candidate geotextile.

(e) One must now do a soil retention analysis to see that soil particles do not embed in the geotextile and decrease its transmissivity. The analysis is the same as presented in the filtration examples.

Geotextile Collector Behind Retaining Wall[2]



Problem: Calculate the number of fabric layers required to drain water from behind the following concrete cantilever retaining wall if θ_{act} = 0.011 [illegible]min-ft fabric. The soil backfill is a [illegible] sand (ML-SW) with k = 0.0098 [illegible]in.

Solution: As before, we proceed in parts:

(a) Calculate the maximum flow rate coming to the geotextile. From the given flow net we have,

$$q = k\,h\,(F/N) = (0.0098)(14)(5.5)(1.0) = 0.14\ \text{ft}^3/\text{min}$$

(b) Determine the flow gradient within the geotextile.

$$i = \sin 90^\circ = 1.0$$

(c) Calculate the required transmissivity using Darcy's formula.

$$\begin{aligned} q &= k\,i\,A \\ &= k\,i\,(t \times w) \\ &= (kt)i(1 \times w) \\ kt &= q/i(1 \times w) \\ &= \frac{0.14}{1.0 \times 1.0} \\ \theta_{reqd} &= 0.14\ \text{ft}^3/\text{min-ft} \end{aligned}$$

(d) Compare this value to the actual geotextile's transmissivity to obtain a factor of safety

$$\begin{aligned} FS &= \frac{\theta}{\theta_{reqd}} \\ &= \frac{0.011}{0.14} \\ &= 0.078 \text{ No Good!} \end{aligned}$$

(e) Since the factor of safety is so low calculate the number of geotextile layers required to handle 0.14 ft³/min-ft wall under the assumptions that multiple layers linearly increase transmissivity (they do not) and a F.S. = 1.0 (which is obviously very poor practice).

$$\text{Number of Layers Required} = \frac{0.14}{0.011} = 13 \text{ Wow!}$$

[illegible] seen is that this application is [illegible]ed for geotextiles. It is how[illegible] a perfect situation for geocomposites (as shown in Figure 1) which [illegible]ive much greater in plane flow ca[illegible]ity.

Summary And Conclusions

Shown in the example problems presented in this paper is that designing with geotextiles is not fundamentally different than traditional geotechnical engineering design without geotextiles. To be sure there are new terms involved, but this is typical of any new material. Once mastered, the design engineer can proceed to calculate a required property, or properties and compare this to the candidate geosynthetic material's property for a factor of safety. If adequate, the search becomes one of locating the least expensive available material. This process is the essence of the "designing by function" method which is recommended. It is believed to be an open, straightforward, rational and honest approach toward selection of the proper geosynthetic material for a specific application.

Regarding the actual designs presented, all focused on the filtration and drainage functions. Here the design philosophy was to allow for free movement of water, yet to retain the upstream soil particles. Both tasks are well within the design state-of-the-art. Not mentioned was the long term compatibility of the soil-fabric-water system, that is, prevention of *complete* clogging of the fabric. In this regard three directions can be taken:

- gradient ratio tests[3]
- long term flow tests[4]
- empirical rules[2]

While beyond the scope and limitations of the present paper these directions can be pursued via the open literature.

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2. Koerner, R. M. and Bell, J. R., *Designing with Geosynthetics*, Prentice-Hall Publ. Co., New York, to appear—1986.
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Fig. 1 Photograph of Geocomposite Materials Having High In-Plane Flow Capabilities.

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Listed below are several methods that have been employed sucessfully on numerous occasions to place POLY-FILTER X (or FILTER-X) below sea level.

1. In one instance a reinforcing rod or pipe is sewn to the seaward edge of the plastic filter cloth. If floating equipment is being used at the job site, the cloth is unrolled beneath the water by being pulled by use of cables from the shore toward the barge. This is illustrated in the enclosed sketch "1-2".

2. Once again sewing the toe edge of the filter sheet to heavy pipe or reinforcing rod, if floating equipment is not available, large rods with a "Y" on the end have been used to push the roll from the shore down the slope beneath water.

3. Again using rod or pipe sewn to the toe edge of the cloth, it has been unrolled beneath the water by skin divers.

   In the three above methods stone has been dropped on the cloth as it is being unrolled. Normally they do not drop the whole cross section of stones as the cloth is being unrolled but just enough to secure it in place until ready to proceed with the next step of construction.

4. In another instance the plastic filter has been sewn to frames of reinforcing rods and then the entire frame placed into position by a crane working from the shoreline. This is illustrated in the enclosed sketch "1-1". When the frames are very large, such as 100 feet by 60 feet, the frame naturally has to be cross braced.

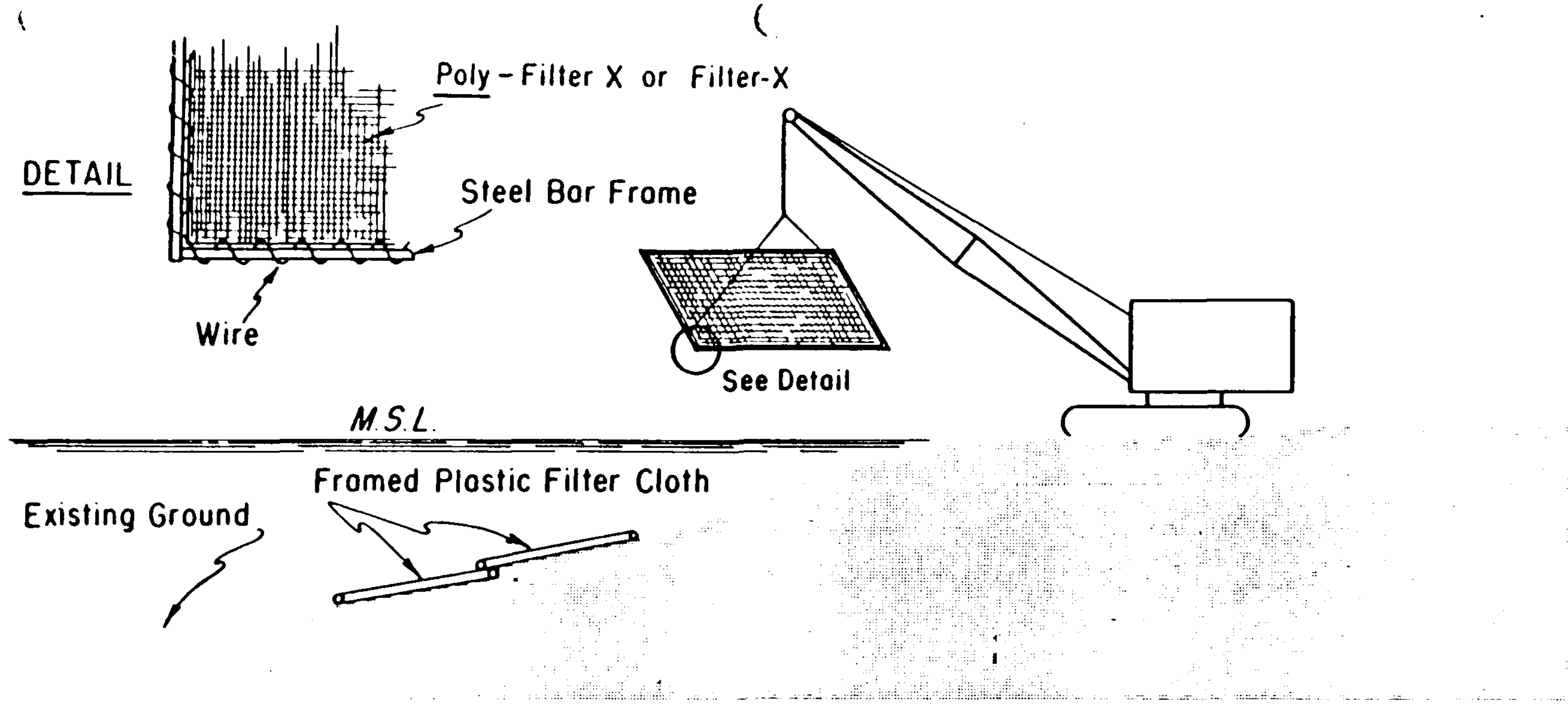
5. Another method has been to secure POLY-FILTER X to a heavy piece of scrap material (such as II beams or metal pipe, sometimes filled with concrete) - making accordion folds the entire length of the cloth against the scrap material, securing the cloth by light strings or wire; attach ropes to each of the two free corners of the cloth - the large bar with the cloth attached is then placed at the design depth on the ocean bottom (or, in the case of a jetty, at the seaward extreme of the structure); the wires holding the cloth in its folds are cut and the ropes are used to pull the cloth up the slope (or shoreward for jetties). This is illustrated by sketch "1-3".

   In all the above methods of installation, it is recommended that the cloth be overlapped 3 feet whenever sheets are to join one another.

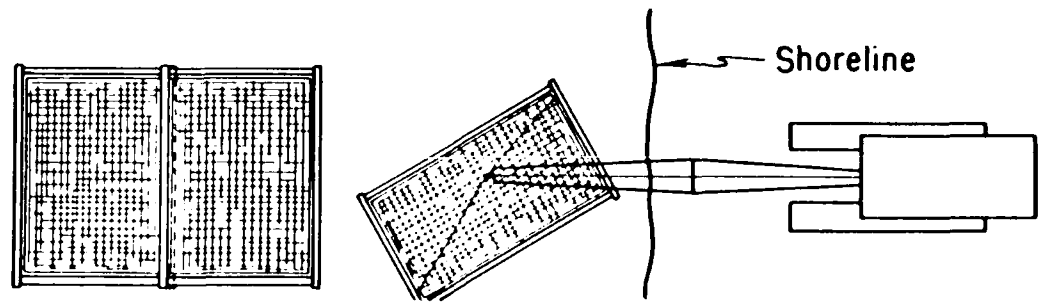
6. If the depth is not too great, the cloth can be unrolled lineally along the shoreline, scattering rock on it as it is being unrolled.

7. Cables are sewn longitudinally to the cloth in several rows (if there is appreciable wave action or turbidity, cables have been sewn to the cloth in a grid pattern), and

the cloth is unrolled down the slope or longitudinally. The flexible cables provide the weight to maintain the position of the cloth and allow it to conform to the irregularities of the bottom or slope. It is not necessary to secure the filter to cables above the expected high water line.



General) Filter cloth is sewn to a frame of reinforcing rod or other weighty material, making sure the cloth is in a loose condition and not stretched so that it can more easily conform to the bottom contours. The frames are picked up by a dragline working from the beach seaward and placed into position beneath water level. After several frames are in position, the dragline places the required base course of rubble and uses this as a roadway to walk upon as the construction continues seaward.



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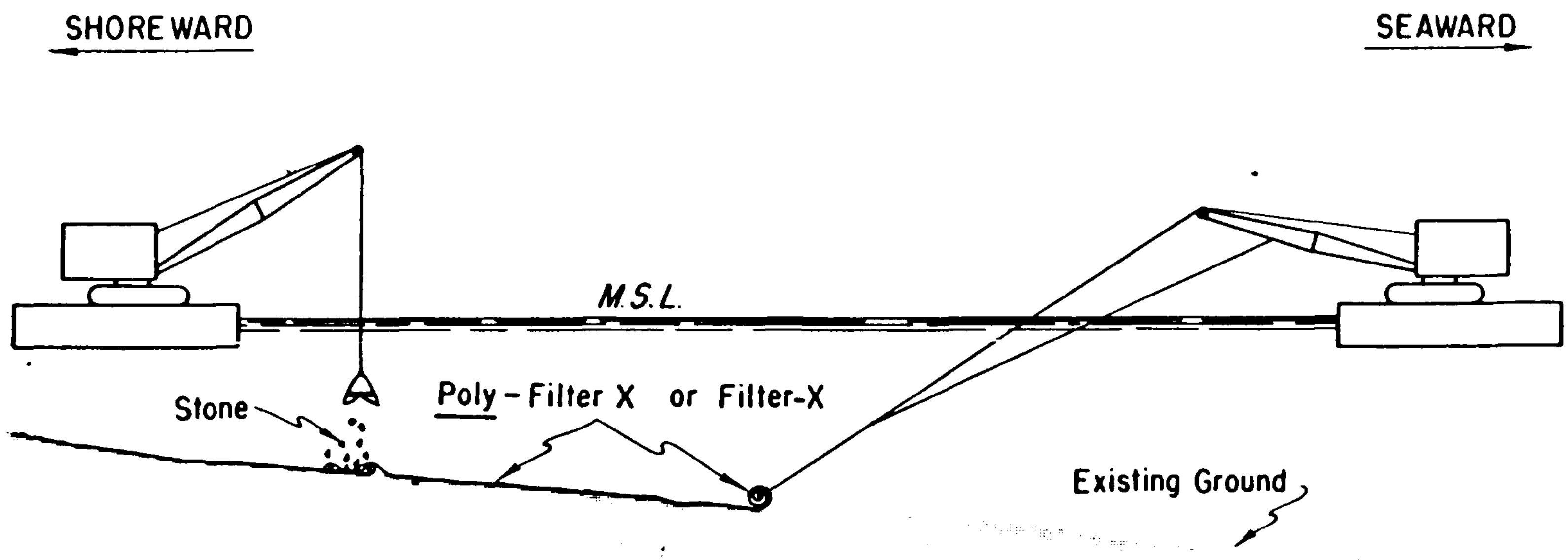
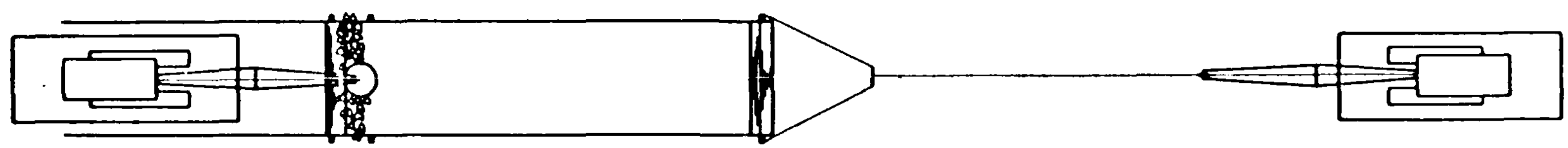
This process is repeated with additional frames being lowered to the bottom, base course being placed on them, and dragline moving out on top of the base course. When the seaward end of the jetty has been reached, the dragline places the upper portion of the structure as it "walks" back to shore. It is supplied with necessary stones to "top off" by trucks using the base course as their roadway.

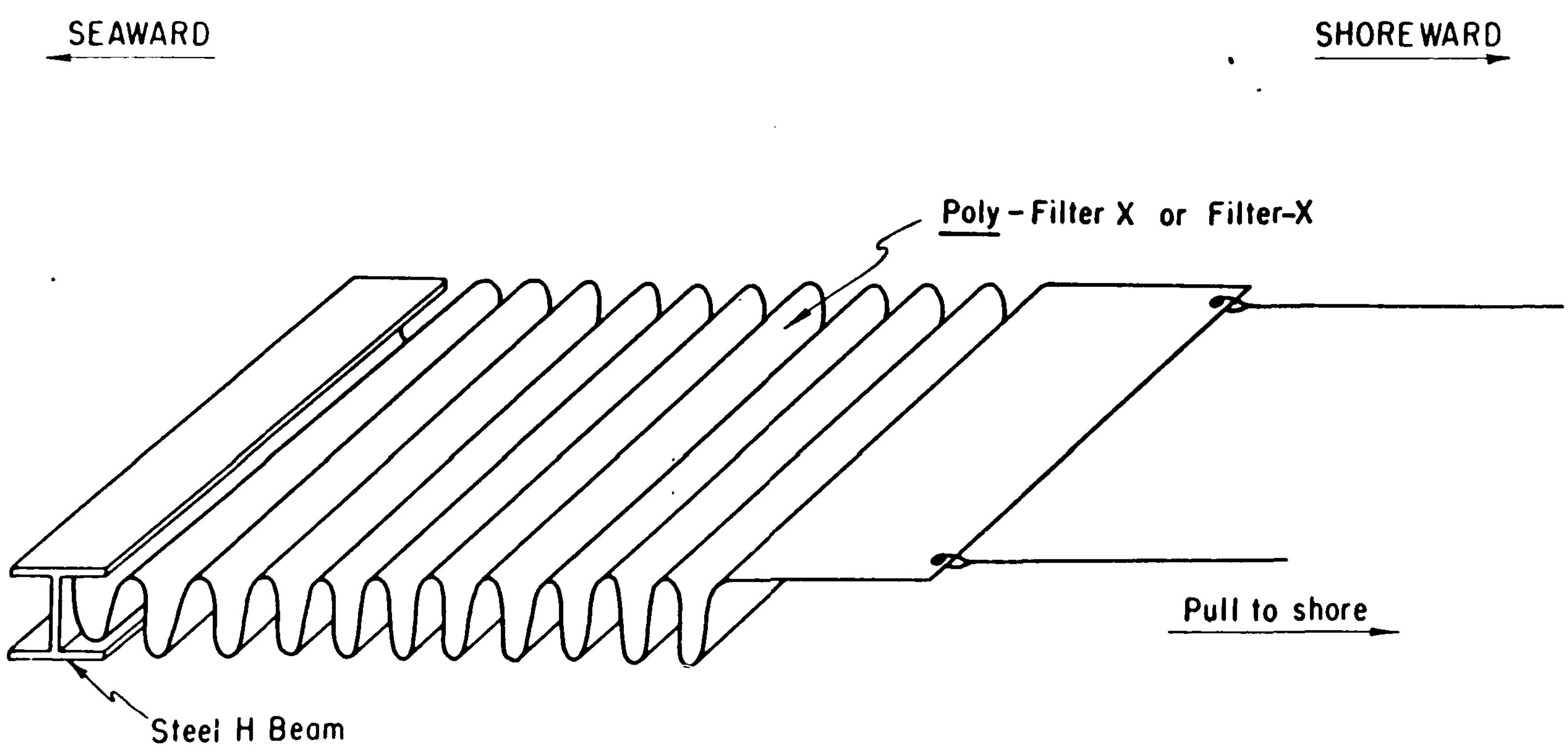


(General) Tubes are sewn into each end of individual sheets of the filter by lapping the cloth back upon itself and then being seamed. Pipes are inserted into these tubes and the filter sheet rolled into a roll on thebeach.

The first roll is then secured to the beach at the shoreward terminus of the jetty; the pipe attached to a yoke on a barge, the cloth is unrolled by pulling the yoke seaward to the barge; when the end of one sheet is reached, the second roll is lowered into position from the barge with a minimum of 2' overlap. The operation is then repeated, unrolling the second section of plastic filter. Small stones, 100-150 lbs.



in weight are randomly dropped onto the filter cloth to hold it in position until ensuing steps of construction are undertaken. Care should be taken to make sure that the overlap is especially well covered with stone so that no peeling of the cloth can occur due to wave and tidal action.



(General) Where tide action is fairly consistent, the filter cloth is secured to an H-beam or other weighty bar and folded accordion style up against the beam. It is then secured to the beam by small pieces of wire. The two free corners of the cloth have ropes attached to them. The beam is then taken to the seaward end of the jetty and lowered into position beneath the water. The wires securing the cloth are cut and men or equipment on the shore pull the cloth shoreward by use of the ropes attached to the free corners.

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The following general installation statements are applicable to both POLY-FILTER X and FILTER-X for applications in revetments and slope stabilization.

1) The plastic filter cloth shall be loosely laid (not stretched) so that it can conform to the irregularities in the embankment when the stone is placed upon it.

2) The stone shall not be dropped from a height greater than ______ feet onto the plastic cloth.

For stones up to 500 lbs. in weight, the drop should be limited to 3 feet.

For stones 500 to 1,000 lbs. in weight, the drop should be limited to 1 foot.

For stones over 1,000 lbs. in weight, the stone should be placed on the cloth, not dropped.

In water depths of 5' or more, stones up to 2 tons may be dropped without damaging the cloth.

3) The filter cloth shall be lapped a minimum of 12 inches.

In some instances this should be 18 inches. This depends upon the type of structure, the construction site, the steepness of the slope, etc. If the cloth is being installed beneath water as a base filter for jetties, groins, or to prevent scour around piers or the legs of drilling rigs, the cloth should be overlapped 5 feet to provide a safety factor.

4) The strips of filter cloth shall be placed (parallel)* or (perpendicular)* to the direction of the flow, or, "to the shoreline" if it is a lake or ocean project.

5) The sheets shall be anchored in place with Carthage Securing Pins inserted thru the cloth along all edges and overlaps. When necessary to adequately secure the plastic cloth, additional Pins may be required in the interior of each panel.

On slopes 4 on 1, or steeper, it is recommended that Pin be placed every 3 feet; on more gentle slopes, every 5 feet.

This refers to construction in the dry only as the Carthage Securing Pins are ineffective in water.

* DELETE ONE.

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Suggested Specification - FILTER-X (method "A")

SECTION _ _

PLASTIC FILTER CLOTH

_ _-1. MATERIALS.

_ _-1.1 Cloth. The plastic filter cloth shall be a pervious sheet woven of polyvinylidene chloride monofilament yarns. The yarn shall consist by weight of at least 85 percent vinylidene chloride and shall contain stabilizers added to the base plastic to make the filaments resistant to deterioration due to ultra-violet and/or heat exposure. After weaving, the cloth shall be calendered so that the filaments retain their relative positions with respect to each other. The cloth shall be free of defects or flaws which significantly affect its physical and/or filtering properties. It shall be woven in widths of 6 feet and in rolls of not less than _ _ _ lineal feet. The sheets of filter cloth shall be sewn together with polypropylene or polyvinylidene chloride thread at the point of manufacture to form sections not less than _ _ feet wide. All edges of the cloth shall be selvaged. The specific gravity shall be 1.70. The plastic filter cloth shall meet all requirements listed in Table 1 *(of this section) (on pg. _) of the specification and have a service record of not less than ten years in projects of a generally similar nature. A competent laboratory must be maintained by the manufacturer of the cloth at the point of manufacture to insure quality control. During shipment and storage, cloth shall be wrapped in burlap.

_ _-1.2 Acceptance, Testing and Requirements. A material equal to the requirements of this specification is FILTER-X produced by Carthage Mills Incorporated, 124 West 66th St., Cincinnati, Ohio 45216. If this plastic filter cloth is selected by the Contractor, he shall furnish the *(Owner) (Contracting Office) (Engineer) ( ) a mill certificate or affidávit from Carthage Mills attesting that the cloth meets the requirements stated in this specification. If the Contractor elects to use a cloth other than the one listed above, he shall furnish samples for testing to the *(Owner) (Contracting Officer) (Engineer) ( ). Samples shall be furnished 60 days prior to installation of the cloth. Samples, shipping and cost of testing shall be at the Contractor's expense. A minimum of 5 square yards of cloth and a minimum of 36 linear inches of seam, with at least one foot of cloth on each side of the seam, shall be furnished for testing. Mill certificates or affidavits, from the producer, shall accompany these samples, citing the trade name and producer of the cloth and certifying that the samples are representative of the material which will be installed at the project and that the manufacturer maintain a laboratory as required in _ _-1.1. In addition, a certified copy of permeability and filtration tests from a qualified laboratory showing the performance of the filter with various grain size soils and water, giving both particle retention and permeability, shall be

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submitted. Also, a service record as required in _ _ -1.1 of the specification.

_ _ -1.3 Securing Pins. The securing pin shall be 3/16 inch diameter steel, pointed at one end, 22 inches long. Not less than six sets of two diametrically opposed "ears" shall be stamped at vertical intervals on the pin shaft. One set of "ears" shall be close to the upper end of the pin and immediately below this set, a steel washer with an outside diameter of 1.5 inches shall be installed. The five additional sets of "ears" shall be at approximately four inch intervals from the upper set.

_ _ -2. INSTALLATION.

_ _ -2.1 Placement. The plastic filter cloth shall be placed in the manner and at the locations shown on the drawings. The surface to receive the cloth shall be prepared to a relatively smooth condition free of obstructions, depressions and debris. The cloth shall not be laid in a stretched condition but shall be laid loosely with the long dimension *(perpendicular) (parallel) to the *(shoreline) (channel centerline). The panels shall be overlapped a minimum of _ _ inches with securing pins inserted through both layers at not greater than _ foot intervals along a line through the approximate midpoint of the overlap. The cloth shall be placed so that the *(lower) (upstream) (lower & upstream) panel will overlap the *(next higher) (downstream) (next higher and downstream) panel. Securing pins shall be placed along a line approximately 2 inches in from the edge of the outer limits of the completed filter cloth area at intervals not greater than _ feet unless otherwise shown on the drawings. Additional pins shall be installed as necessary to prevent any slippage of the filter cloth, regardless of location. Each securing pin shall be inserted through the cloth until the washer bears against the cloth and secures it firmly to the foundation. No more than _ horizontal overlaps shall be permitted. Vertical overlaps shall be staggered a minimum of 5 feet. Stone shall not be dropped on the cloth from a height greater than _ feet.

_ _ -2.2 Damage. Plastic filter cloth damaged or displaced before or during installation or during placement of overlying layers of *(bedding) (riprap) (stone) shall be replaced or repaired to the satisfaction of the *(Owner) (Contracting Officer) (Engineer) ( ) at the Contractor's expense.

_ _ -2.3 Measurement. Plastic filter cloth shall be measured for payment by the square foot in place. Overlaps shall be measured as a single layer of cloth. No separate payment shall be made for shipping, handling, storage, seams, special fabrication, weighting devices, securing pins or installation. All costs incidental to construction of cloth shall be included in the contract price for "Plastic Filter Cloth".

TABLE 1

(F-X, method "A")

REQUIREMENTS FOR PLASTIC FILTER CLOTH

TEST	METHOD	REQUIREMENTS	
Breaking Load & Elongation	ASTM D 1682, Grab Test Method, constant rate of travel 12" per min., elongation between 10% and 35%	tensile strength**	
		stronger principal direction	200 lbs.
		weaker principal direction	110 lbs.
Oxygen Pressure	CRD-C 577 or 711 in Fed. Std. 601	tensile strength**	
		stronger principal direction	200 lbs.
		weaker principal direction	110 lbs.
Effect of Alkalies	Special***	tensile strength**	
		stronger principal direction	190 lbs.
		weaker principal direction	105 lbs.
Effect of Acids	Special***	same as Oxygen Pressure requirement	
Low Temperature	Special***	same as Oxygen Pressure requirement	
High Temperature	Special***	same as Oxygen Pressure requirement	
Weight Change in Water	CRD-C 575 or 6631 in Fed. Std. 601	less than 1%	
Brittleness	CRD-C 570 or 5311.1 in Fed. Std. 601	no failure at minus 60^{o} F	
Freeze-Thaw	CRD-C 20 300 cycles, each cycle 2 hrs.	tensile strength**	
		stronger principal direction	195 lbs.
		weaker principal direction	105 lbs.
Weatherometer	ASTM G 23 250 cycles using type D or DH equipment	tensile strengths**	
		stronger principal direction	170 lbs.
		weaker principal direction	110 lbs.

TABLE 2

REQUIREMENTS FOR PLASTIC FILTER CLOTH

TEST	METHOD	REQUIREMENTS
Bursting Strength	ASTM D 751, using Diaphragm Bursting Tester	260 lbs. per sq. in.
Puncture Strength	ASTM D 751, modified***	70 lbs.
Seam Breaking Strength	ASTM D 1683	80 lbs.
Abrasion Resistance	ASTM D 1175, modified***	tensile strength** stronger principal direction 57 lbs. weaker principal direction 19 lbs.
Percent of Open Area	Special***	not less than 4% not more than 5%
Equivalent Opening Size (E. O. S.)	Special***	U. S. Standard Sieve No. 100
Permeability	Special***	4.8×10^{-2} cm/sec.

** Tensile strength determined by Breaking Load & Elongation by the method stated in the first listing of Table 1.

*** These METHODS *(available at the office of the *(Owner) (Contracting Officer) (Engineer) (are listed on pages __ thru __ of this specification)

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Suggested Specification - POLY-FILTER X (method "B")

SECTION _ _

PLASTIC FILTER CLOTH

_ _-1. MATERIALS.

_ _-1.1 Cloth. The plastic filter cloth shall be a pervious sheet woven of polypropylene monofilament yarns. The yarn shall consist by weight of at least 85 percent propylene and contain stabilizers and inhibitors added to the base plastic to make the filaments resistant to ultra-violet and heat deterioration. After weaving, the cloth shall be calendered and palmered so that the filaments retain their relative positions with respect to each other. All edges of the cloth shall be selvaged and/or serged. The plastic filter shall be free of defects or flaws which significantly affect its physical and/or filtering properties. The filter cloth shall meet all requirements listed in TABLE 1 *(of this section) (on pg. _ _). A competent laboratory must be maintained by the producer of the cloth at the point of manufacture to insure quality control.

_ _-1.2 Service Record Requirement. To satisfy the requirements of this specification the plastic filter cloth must have a service record of not less than 10 years in projects of a generally similar nature.

_ _-1.3 Acceptance, Testing and Requirements. POLY-FILTER X produced by Carthage Mills Incorporated, 124 West 66th St., Cincinnati, Ohio 45216 meets the requirements of this specification; therefore if this cloth is selected by the Contractor, he shall furnish the *(Owner) (Contracting Office) (Engineer) ( ) a mill certificate from Carthage Mills Incorporated attesting that the cloth meets the requirements stated in the specification. If the Contractor elects to use a cloth other than the one listed above, he shall furnish the *(Owner) (Contracting Officer) (Engineer) ( ) with samples for testing. Samples shall be furnished 60 days prior to installation of the cloth. Samples, shipping and cost of testing shall be at the Contractor's expense. A minimum of 5 square yards of cloth and a minimum of 36 linear inches of seam, with at least one foot of cloth on each side of the seam, shall be furnish-

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ed for testing. Mill certificates from the producer, shall accompany these samples, citing the trade name and producer of the cloth and certifying that the samples are representative of the material which will be installed at the project, and that a competent laboratory is maintained at the point of manufacture. In addition, a certified copy of permeability and filtration tests from a qualified laboratory showing the performance of the filter with various grain size soils and water, giving both particle retention and permeability, shall be submitted. Also, a service record as required in _ _ -1.2 of this specification.

_ _ -1.4 Securing Pins. The securing pins shall be 3/16 inch diameter steel, pointed at one end, 22 inches long. Not less than six sets of two diametrically opposed "ears" shall be stamped at vertical intervals on the pin shaft. One set of "ears" shall be close to the upper end of the pin and immediately below this set, a steel washer with an outside diameter of 1.5 inches shall be installed. The five additional sets of "ears" shall be at approximately four inch intervals from the upper set.

(Suggested Specification - POLY-FILTER X - method "B")

TABLE 1

REQUIREMENTS FOR PLASTIC FILTER CLOTH

TEST	METHOD	REQUIREMENTS
Breaking Load & Elongation	ASTM D 1682, Grab Test Method, constant rate of travel 12" per min.	tensile strength: stronger principal direction 375 lbs. weaker principal direction 220 lbs. elongation between 10% & 35%
Weight Change in Water	CRD-C 575 or 6631 in Fed. Std. 601	less than 1%
Bursting Strength	ASTM D 751, using Diaphragm Bursting Tester	535 lbs. per sq. in.
Puncture Strength	ASTM D 751, modified**	140 lbs.
Seam Breaking Strength	ASTM D 1683, 1" square jaws, constant rate of traverse 12" per min.	195 lbs.
Abrasion Resistance	ASTM D 1175, modified**	tensile strength*** stronger principal direction 100 lbs. weaker principal direction 68 lbs.
Percent of Open Area	Special**	not less than 5% not more than 6%
Equivalent Opening Size	Special**	U. S. Standard Sieve No. 70
Permeability		3.3 and 3.8 x 10^{-2} cm/sec.

Specific Gravity 0.95

Weight Approx. .05 lb./sq. ft.

Seams sewn with polypropylene thread at point of manufacture

Packaged in burlap

Minimum filter cloth width __ feet

Minimum filter cloth length ___ feet

** se METHODS *(available at the office of the (Owner) (Contracting Officer) (Engineer) are listed on pages __ thru __ of this specification)

*** Tensile strength determined by Breaking Load & Elongation by the method stated in the first listing of Table 1.

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Suggested Specification - POLY-FILTER X (method "C")

SECTION _ _

PLASTIC FILTER CLOTH

_ _-1. MATERIALS.

_ _-1.1 Cloth. The plastic filter cloth shall be a pervious sheet woven of polypropylene monofilament yarns. The yarn shall consist by weight of at least 85 percent propylene and shall contain stabilizers and inhibitors added to the base plastic to make the filaments resistant to deterioration due to ultra-violet and/or heat exposure. After weaving, the cloth shall be calendered and palmered so that the filaments retain their relative positions with respect to each other. The cloth shall be free of defects or flaws which significantly affect its physical and/or filtering properties. Filter cloth shall be woven in widths of 6 feet and furnished in rolls not less than _ _ _ lineal feet. The sheets of cloth shall be sewn together with polypropylene thread at the point of manufacture to form sections not less than _ _ feet wide. All edges of the cloth shall be selvaged or serged. The specific gravity shall be 0.95. The plastic filter cloth shall meet all requirements listed in TABLE 1 *(of this section) (on pg. _) of this specification and have a service record of not less than ten years in projects of a generally similar nature. A competent laboratory must be maintained by the producer of the cloth at the point of manufacture to insure quality control. During shipment and storage, cloth shall be wrapped in burlap.

_ _-1.2 Acceptance, Testing and Requirements. A material equal to the requirements of this specification is POLY-FILTER X produced by Carthage Mills Incorporated, 124 West 66th St., Cincinnati, Ohio 45216. If this plastic filter cloth is selected by the Contractor, he shall furnish the *(Owner) (Contracting Office) (Engineer) ( ) a mill certificate from Carthage Mills Incorporated attesting that the cloth meets the requirements stated in the specification. If the Contractor elects to use a cloth other than the one listed above, he shall furnish the *(Owner) (Contracting Officer) (Engineer) ( ) with samples for testing. Samples shall be furnished 60 days prior to installation of the cloth. Samples, shipping and cost of testing shall be at the Contractor's expense. A minimum of 5 square yards of cloth and a minimum of 36 linear inches of

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seam, with at least one foot of cloth on each side of the seam, shall be furnished for testing. Mill certificates from the producer, shall accompany these samples, citing the trade name and producer of the cloth and certifying that the samples are representative of the material which will be installed at the project, and that a competent laboratory is maintained at the point of manufacture. In addition, a certified copy of permeability and filtration tests from a qualified laboratory showing the performance of the filter with various grain size soils and water, giving both particle retention and permeability, shall be submitted. Also, a service record as required in _ _ -1.1 of this specification.

_ _ -1.3 Securing Pins. The securing pin shall be 3/16 inch diameter steel, pointed at one end, 22 inches long. Not less than six sets of two diametrically opposed "ears" shall be stamped at vertical intervals on the pin shaft. One set of "ears" shall be close to the upper end of the pin and immediately below this set, a steel washer with an outside diameter of 1.5 inches shall be installed. The five additional sets of "ears" shall be at approximately four inch intervals from the upper set.

(Suggested Specification - POLY-FILTER X - method "C")

TABLE 1

REQUIREMENTS FOR PLASTIC FILTER CLOTH

TEST	METHOD	REQUIREMENTS
Breaking Load & Elongation	ASTM D 1682, Grab Test Method, constant rate of travel 12" per min.	tensile strength: stronger principal direction 375 lbs. weaker principal direction 220 lbs. elongation between 10% & 35%
Oxygen Pressure	CRD-C 577 or 711 in Fed. Std. 601	same as Breaking Load & Elongation**
Effect of Alkalis	Special***	same as Breaking Load & Elongation**
Effect of Acids	Special***	tensile strength:** stronger principal direction 350 lbs. weaker principal direction 210 lbs. elongation between 10% & 35%
Low Temperature	Special***	same as Effect of Acids**
High Temperature	Special***	same as Effect of Acids**
Weight Change in Water	CRD-C 575 or 6631 in Fed. Std. 601	less than 1%
Brittleness	CRD-C 570 or 5311.1 in Fed. Std. 601	no failure at minus 60° F

** Tensile strength determined by Breaking Load & Elongation by the method stated in the first listing of Table 1.

*** These METHODS *(available at the office of the (Owner) (Contracting Officer) (Engineer) are listed on pages __ thru __ of this specification)

(over)

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Suggested Specification - POLY-FILTER X (method "D")

SECTION _ _

PLASTIC FILTER CLOTH

_ _-1. MATERIALS.

_ _-1.1 Cloth. The plastic filter cloth shall be a pervious sheet woven of polypropylene monofilament yarns. The yarn shall consist by weight of at least 85 percent propylene and shall contain stabilizers and inhibitors added to the base plastic to make the filaments resistant to deterioration due to ultra-violet and/or heat exposure. After weaving, the cloth shall be calendered and palmered so that the filaments retain their relative positions with respect to each other. The cloth shall be free of defects or flaws which significantly affect its physical and/or filtering properties. Filter cloth shall be woven in widths of 6 feet and furnished in rolls not less than _ _ _ lineal feet. The sheets of cloth shall be sewn together with polypropylene thread at the point of manufacture to form sections not less than _ _ feet wide. All edges of the cloth shall be selvaged or serged. The specific gravity shall be 0.95. The plastic filter cloth must have a satisfactory service record of not less than ten years in projects of a generally similar nature. A competent laboratory shall be maintained by the producer of the cloth at the point of manufacture to insure quality control. During shipment and storage, cloth shall be wrapped in burlap.

_ _-1.2 Previously Approved Cloth. POLY-FILTER X produced by Carthage Mills Incorporated, 124 West 66th St., Cincinnati, Ohio 45216 is equal to the requirements of the specification. If this plastic filter cloth is selected by the Contractor, he shall furnish the *(Owner) (Contracting Office) (Engineer) ( ) a mill certificate from Carthage Mills Incorporated attesting that the cloth meets all requirements stated in this specification.

_ _-1.3 Other Filter Cloths. If the Contractor elects to use a cloth other than the one listed in _ _-1.2 of this specification, he shall furnish the *(Owner) (Contracting Officer) (Engineer) ( ) with samples for testing 60 days prior to initial instal-

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(over)

lation of the cloth. Sampling, shipping and cost of testing samples shall be at the Contractor's expense. A minimum of 5 square yards of cloth and a minimum of 36 linear inches of seam, with at least one foot of cloth on each side of the seam, shall be furnished for testing in accordance with _ _ -1. 1 of this specification. Mill certificates from the producer shall accompany these samples, citing the trade name and producer of the cloth and certifying that the samples are representative of the material which will be installed at the project. In addition the producer shall submit a service record as required in _ _ -1.1 and certify that a competent laboratory is maintained at the point of manufacture.

_ _ -1.4 Acceptance Testing for Plastic Filter Cloth.

_ _ -1.4.1 Breaking Load and Elongation Test. Five warp and five fill samples, unaged, shall be tested in accordance with method ASTM D 1682 using the Grab Test Method. The jaws shall be 1 inch square and the constant rate of travel 12 inches per minute. The strength in the stronger principal direction shall be not less than 375 pounds and in the weaker principal direction not less than 220 pounds. The elongation at failure shall be between 10 and 35 percent.

_ _ -1.4.2 Weight Change in Water. Five warp and five fill samples, 4 $\pm$ 0.2 inches by 6 $\pm$ 0.2 inches, unaged, shall be tested using method CRD-C 575 or method 6631 in Fed. Std. 601. The percent absorption shall be determined by dividing the difference in weight of the sample before and after immersion by the weight of the sample before. The weight increase shall not exceed one percent.

_ _ -1.4.3 Bursting Strength. Five samples, unaged, shall be tested in accordance with method ASTM D 751 and the bursting strength determined using the Diaphragm Bursting Tester. The strengths shall be not less than 535 pounds per square inch gage.

_ _ -1.4.4 Puncture Strength. Five samples, unaged, shall be tested using method ASTM D 751, and the puncture strength determined using the Tension Testing Machine With Ring Clamp, except that the steel ball shall be replaced with a 5/16-inch diameter solid steel cylinder centered within the ring clamp. The strengths shall be not less than 140 pounds.

_ _ -1.4.5 Seam Breaking Strength. Five samples, unaged, shall be tested in accordance with method ASTM D 1683, using 1-inch square jaws and 12 inches per minute constant rate of traverse. The strengths shall be not less than 195 pounds.

_ _ -1.4.6 Abrasion Resistance. Five warp and five fill samples, unaged, shall be tested in accordance with method ASTM D 1175, using the "Rotary Platform, Double Head" method. The abrasive wheels will be the rubber-base type equal to the CS-17 "Calibrase" manufactured by Taber Instrument Company. The load on each wheel shall be 1000 grams and the test shall be continued for 1000 revolutions. Samples then shall be tested using method ASTM D 1682 except as modified by _ _ -1.4.1. The strength in the stronger principal direction shall be not less than 100 pounds and in the weaker principal direction not less than 68 pounds.

__ -1.4.7 Determination of Open Area. Each of five samples, unaged, shall be placed separately in a 2-inch by 2-inch glass slide holder and the image projected with a slide projector on a screen. A block of 25 openings near the center of the image shall be selected and the length and width of each of the 25 openings and the widths of the fibers adjacent to the openings shall be measured to the nearest 0.001-inch. The percent open area is determined by dividing the sum of the open areas of the 25 openings by the sum of the total area of the 25 openings and their adjacent fibers. The open area shall be not less than 5 percent and not more than 6 percent.

__ -1.4.8 Determination of Equivalent Opening Size (E.O.S.). Five unaged samples shall be tested. Obtain about 150 gm of each of the following fractions of a sand composed of sound rounded particles:

U. S. Standard Sieve Number

Passing	Retained On	Passing	Retained On	Passing	Retained On
10	20	30	40	50	70
20	30	40	50	70	100
				100	120

The cloth shall be affixed to a standard sieve having openings larger than the coarsest sand used in such a manner that no sand can pass between the cloth and the sieve wall. The sand shall be oven dried. Shaking shall be accomplished as described in paragraph 2d (1) (g), Appendix V, EM 1110-2-1906, except shaking shall be continued for 20 minutes. Determine by sieving (using successively coarser fractions) that fraction of sand of which 5 percent or less by weight passes the cloth; the equivalent opening size of the cloth sample is the "retained on" U. S. Standard Sieve number of this fraction. The E.O.S. shall be no finer than the U. S. Standard Sieve No. 80 and no coarser than the U. S. Standard Sieve No. 60.

__ -1.5 Securing Pins. The securing pin shall be 3/16 inch diameter steel, pointed at one end, 22 inches long. Not less than six sets of two diametrically opposed "ears" shall be stamped at vertical intervals on the pin shaft. One set of "ears" shall be close to the upper end of the pin and immediately below this set, a steel washer with an outside diameter of 1.5 inches shall be installed. The five additional sets of "ears" shall be at approximately four inch intervals from the upper set.

END

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